1978

Production and distribution effects of blending coal: an Iowa case study

Craig Weston O'Riley
Iowa State University

Production and distribution effects of blending coal: An Iowa case study

by

Craig Weston O'Riley

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Department: Economics
Major: Agricultural Economics

Iowa State University
Ames, Iowa

1978

TABLE OF CONTENTS

CHAPTER I. INTRODUCTION AND OBJECTIVES

Introduction

During the mid 1900's, the United States switched from coal to oil and natural gas as the main energy sources. Oil and natural gas are currently providing about 75 percent of the energy consumed in the United States. However, coal represents 90 percent of the nation's proven energy reserves (7). Declining domestic oil and natural gas reserves, increasing energy consumption, and increasing costs of imported energy have created a renewed interest in coal reserves and nuclear power as major sources of energy. However, cost and environmental concerns about nuclear power suggest that coal may be the primary resource to increase the nation's short run energy self-sufficiency.

Even though there is a renewed interest in coal, the Iowa coal industry is experiencing declining production in a period of increasing Iowa demand. Table 1.1 presents Iowa's consumption and production in the 1970's. Iowa's consumption rose nearly two million tons from 1970 to 1976. An Iowa State University survey of Iowa industrial, utility, and institutional coal users which consume at least 1,000 tons of coal per year indicates that 16 million tons of coal are expected to be consumed in 1980 and approximately 18.5 million tons of coal are expected to be consumed in 1985. Thus, in 1980, total

Table 1.1. Tons of coal consumed and produced in Iowa in the 1970's (14)

Year	Consumption	Production
1970	6,159,000	987,000
1971	6,239,000	1,017,000
1972	6,956,000	764,000
1973	6,889,000	658,000
1974	6,589,000	597,000
1975	6,741,000	644,000
1976	7,894,000	540,000

coal consumption is expected to be double the amount consumed in 1976. However, Iowa's coal production continues to decline from 987,000 tons in 1970 to 540,000 tons in 1976.

Iowa users received 7.9 million tons of coal in 1976. Iowa coal accounted for only seven percent of the coal received by Iowa coal users. The major origins of coal for Iowa users in 1976 is presented in Table 1.2. Of the 7.9 million tons received in 1976, 41 percent originated in Wyoming and 36 percent originated in Illinois. Six percent came from Missouri and three percent originated in Western Kentucky.

Stringent environmental standards on sulfur dioxide

Table 1.2. Quantity of coal shipped to Iowa by origin state in tons, 1976 (15)

Origin	Tons	Percent
Wyoming, Idaho	3,227,000	40.88
Illinois	2,839,000	35.96
Iowa	540,000	6.84
Missouri, Kansas, Texas, Oklahoma	485,000	6.14
Western Kentucky	215,000	2.72
Appalachia	26,000	0.33
All others	562,000	7.12
TOTAL	7,894,000	100.00

emissions was cited by all contacted Iowa miners as a main reason for the poor condition of the Iowa coal market (5). Other reasons that may explain the decline in Iowa's mining while Iowa's coal consumption increases are:

1. high sulfur content of Iowa coal,
2. pyrite and rock in Iowa coal causing high maintenance costs on equipment,
3. deep underground location and thinness of Iowa coal seams, and
4. small scale of Iowa mining operations and relatively high costs.

Other factors that may have contributed to the decline are the discovery of vast deposits of low sulfur coal in the west and relatively low unit-train rail rates on the western coal.

Several methods may tend to improve the competitive position of the Iowa coal industry. One method may be to reduce the sulfur content and other impurities through coal beneficiation plants. The experimental beneficiation plant operated by Iowa State University has been able to reduce the sulfur content of Iowa coal by about 35 percent. Beneficiation is a process where crushed coal is passed through water. Since coal and pyritic sulfur have different specific gravities, this process allows the sulfur to be separated out.

Another method to improve the Iowa coal market is to reduce the transportation cost of Iowa coal to users compared to the cost of transporting coal from non-Iowa origins to Iowa users. Improvements in transporting Iowa coal may include using alternative truck types, truck-rail combinations, truck-barge combinations, and larger sizes of rail shipments.

Another method may be to blend the high sulfur Iowa coal with a low sulfur coal such as Wyoming coal. Some utilities are currently blending a high sulfur Iowa coal with a low sulfur Wyoming coal to achieve an acceptable level of sulfur content. The typical method currently used to blend Iowa coal with low sulfur coal is to dump a front-end loader scoop of Iowa coal and then another scoop of low sulfur coal into the reclaim hopper. This method creates variations in Btu's or heating value to the boilers causing the steam pressure to vary. To eliminate the variations, layering the coals has been used where one car load of coal is spread over another car load of coal in a storage pile. However, this method does not seem to be very effective in eliminating the variation in Btu's. One possibility to eliminate this variation is to mechanically blend the two coal types. Blending plants could be constructed to receive the two coals, store them in separated piles, reclaim the two coal types separately at the same time, blend the coal to specific qualities, and load-out the blended coal. A conveyer system which would include belt scales and samplers to achieve accurate blend types would blend the coals. Under this process, the optimal number and location of blending plants must be determined if the position of the Iowa industry is to be improved.

Objectives

The basic objective of this study is to evaluate the economic impact of coal blending plants on the transportation and distribution systems in Iowa. The specific objectives of this study are to:

1. estimate investment and operating costs of coal blending plants,
2. estimate transportation costs from coal origins to blending plants and from blending plants to each

major Iowa coal user,

3. estimate potential blend types from blending a high sulfur coal with a low sulfur coal to be shipped from a blending plant to a user, and
4. estimate the optimal amount of coal transported from each coal origin to each Iowa coal user, the optimal modes of transportation from origin to user, identify users who would expand coal receiving capacities, the optimal number and location of coal beneficiation plants, and the optimal number and location of coal blending plants under a coal blending alternative.

This analysis is an extension of an analyses done by C. Phillip Baumel, Thomas P. Drinka, and John J. Miller at Iowa State University in 1978 (2). The analysis in this thesis compares the optimal blending solution with a solution from the Baumel et al. report which is based on estimated multiple-car rail rates and an average FOB Iowa mine price $17.33 per ton.

Literature Review

Boehlje and Libbin (4) specified factors that affect the competitive nature of the Iowa coal industry. A computer model was used to evaluate alternative mining and transportation cost, availability of mining equipment, coal processing, sulfur dioxide emission standards, and coal demand.

Results indicated increased Iowa production in the short run under most alternatives. However, dramatic changes must take place before Iowa production can compete in the long run.

Eldridge (6) used a mixed integer-linear programming model to determine the optimal number and location of coal beneficiation plants in Iowa to evaluate the impact on Iowa coal production and transportation. The results included production of 3,290,000 tons of raw Iowa strip mine coal to be beneficiated at four plants under 1977 FOB mine prices and current Ex Parte 336 rail rates.

Baumel, Drinka, and Miller (2) used a mixed integer-linear programming model to evaluated alternative Iowa coal transportation and distribution systems based on alternative coal prices, rail rates, and truck weight limits. The results indicated increased Iowa coal production with one to three beneficiation plants under both current Ex Parte 336 rail rates and estimated 1977 multiple car rail rates depending on the FOB mine prices used.

Hanline (8) used a mixed integer-linear programming model to determine the number and locations for coal blending plants in Indiana. The emphasis was placed on the efficiency of the transportation network. The results included six blending plants to serve the selected 15 consumer areas in Indiana.

CHAPTER II. METHOD OF ANALYSIS

The model used is an extension to the model used in a recent coal transportation study at Iowa State University (2). The extension consists of modifying the mixed integer-linear programming model to include the possibility of mechanically blending Iowa coal with out-of-state coals for use by Iowa coal users. The mixed integer-linear programming model determines the optimal number and location of coal blending plants from the possible plant sites, the optimal number and location of coal beneficiation plants from the possible plant sites, and which users should upgrade their receiving capacity to the next larger rail shipment size. The objective function of the model minimizes the cost of supplying Iowa users' 1980 coal consumption subject to constraints on mining capacity, beneficiation plant capacity, blending plant capacity, receiving capacity of users, sulfur dioxide emission standards, and projected 1980 Iowa coal consumption. The model uses continuous variables for mining, beneficiation, blending, and transportation activities; and zero-one integer variables for construction of beneficiation plants, construction of blending plants, and expansion of user rail receiving capacities.

The model is summarized as follows:

$$
\begin{aligned}
\text{Minimize } Z = {} & \sum_i P_i M_i + \sum_i \sum_k \sum_m a_{ikm} U_{ikm} + \Psi \sum_i \sum_j b_{ij} \Big[\sum_k \sum_m V1_{ijkm} \\
& + \sum_n \sum_m V2_{ijnm} \Big] + (\Psi - 1) \sum_j \sum_i c_{ji} \Big[\sum_k \sum_m V1_{ijkm} + \sum_n \sum_m V2_{ijnm} \Big] \\
& + \alpha \sum_i \sum_j \Big[\sum_k \sum_m V1_{ijkm} + \sum_n \sum_m V2_{ijnm} \Big] + \sum_i \sum_j \sum_k \sum_m d_{jkm} V1_{ijkm} \\
& + \sum_j FC_j Y_j + \sum_k EC_k X_k + \sum_i \sum_n \sum_m e_{inm} L_{inm} + \sum_i \sum_j \sum_n \sum_m f_{jnm} V2_{ijnm} \\
& + \sum_n BFC_n W_n + \beta \Big[\sum_i \sum_n \sum_m L_{inm} + \sum_i \sum_j \sum_n \sum_m V2_{ijnm} \Big] \\
& + \sum_n \sum_k \sum_m \sum_q g_{nkm} R_{nkmq} \qquad (2.1)
\end{aligned}
$$

where

Z = total cost,

P_i = price per unit of coal at mine i,

M_i = volume of coal supplied by mine i,

a_{ikm} = transportation plus variable receiving cost per unit of coal shipped from mine i to user k by mode m,

U_{ikm} = volume of coal shipped from mine i to user k by mode m,

Ψ = inverse of the fractional weight recovery at beneficiation plants,

b_{ij} = transportation cost per unit of coal shipped from mine i to beneficiation plant j,

c_{ij} = transportation cost per unit of refuse shipped from beneficiation plant j to mine i,

$V1_{ijkm}$ = volume of clean coal equivalent shipped from mine i to beneficiation plant j to user k by mode m,

$V2_{ijnm}$ = volume of clean coal equivalent shipped from mine i to beneficiation plant j to blender n by mode m,

α = variable beneficiation cost per unit of clean coal,

d_{jkm} = transportation plus variable receiving cost per unit of clean coal shipped from beneficiation plant j to user k by mode m,

FC_j = annual fixed cost of establishing a beneficiation plant at site j,

Y_j = (0,1), a binary variable. If beneficiation plant j is used, $Y_j = 1$, otherwise $Y_j = 0$,

EC_k = annual fixed cost of expanding the rail receiving capacity of user k to the next larger size,

X_k = (0,1), a binary variable, if user k expands its rail receiving capacity, $X_k = 1$, otherwise $X_k = 0$,

e_{inm} = transportation cost per unit of coal shipped from mine i to blending plant n by mode m,

L_{inm} = volume of coal shipped from mine i to blending plant n by mode m,

f_{jnm} = transportation cost per unit of clean coal shipped from beneficiation plant j to blending plant n by mode m,

BFC_n = annual fixed cost of establishing a blending plant at site n,

W_n = (0,1), a binary variable. If blending plant n is used, $W_n = 1$, otherwise $W_n = 0$,

β = variable blending cost per unit of coal,

g_{nkm} = transportation plus variable receiving cost per unit of coal shipped from blending plant n to user k by mode m,

R_{nkmq} = volume of coal of quality q shipped from blending plant n to user k by mode m.

The model includes 33 potential coal mines to meet the 46 major coal users' projected consumption in 1980. Users' consumption can be satisfied by receiving coal directly from Iowa underground mines, non-Iowa coal mines, beneficiation plants, blending plants, or any combination. Iowa strip mine coal cannot be used directly by users due to its quality. Therefore, this raw strip mine coal must either be beneficiated or blended before users can burn it.

The model includes barge, truck, single-car rail, 15-car rail, 50-car rail, and 100-car unit train as transportation modes from mines to users. Each user has the option of receiving the coal by the least costly mode, subject to its existing modal receiving capacity. Only those users who currently have barge receiving facilities were given access to barge rates. A coal user incurs an additional annual fixed cost if it expands its rail receiving capacity to the next larger shipment size.

The possible transportation modes from beneficiation plants to users are truck, single-car rail, 15-car rail, and 50-car rail. Each user has the option of receiving coal by the least costly transportation mode. The cost of beneficiating Iowa coal includes the total annual cost of constructing a plant plus the variable cost of operation. Since raw Iowa strip mine coal is not allowed to be transported directly to users, it must be shipped by truck from the mine to a beneficiation plant. The cost of transporting the refuse from the beneficiation plant to the mine is added to the cost of beneficiating Iowa coal.

The transportation modes used from blending plants to users are truck, single-car rail, 15-car rail, and 50-car rail. Each user has the option of receiving coal by the least costly transportation mode. The cost of blending coal includes the total annual fixed cost of establishing a blending plant, the variable cost of operating the plant, the cost of transporting raw Iowa strip-mined coal to the blending plant, the cost of transporting non-Iowa coal to the blending plant, and the cost of transporting beneficiated Iowa coal from a beneficiation plant to a blending plant.

The following constraints were imposed on the model:

1. The volume of coal shipped from a mine cannot exceed the supply capacity of that mine.

$$\sum_k \sum_m U_{ikm} + \Psi \sum_j \sum_k \sum_m V1_{ijkm} + \Psi \sum_j \sum_n \sum_m V2_{ijnm}$$
$$+ \sum_n \sum_m L_{inm} = M_i \leq MC_i \qquad (2.2)$$

where

MC_i = total supply capacity of mine i.

2. The volume of coal beneficiated at a plant cannot exceed the beneficiation plant capacity.

$$\sum_i \sum_k \sum_m V1_{ijkm} + \sum_i \sum_n \sum_m V2_{ijnm} \leq BC_j \qquad (2.3)$$

where

BC_j = beneficiation plant capacity in units of clean coal at site j.

3. The demand for coal at each user must be satisfied. Demand was specified in heating value rather than tons to account for the differences in heating values of coal from the different mines.

$$\sum_i \sum_m B_i U_{ikm} + \sum_i \sum_j \sum_m \Omega_i V1_{ijkm} + \sum_n \sum_m \sum_q \gamma_{kq} R_{nkmq} \geq D_k \qquad (2.4)$$

where

B_i = heating value per unit of raw coal from mine i,

Ω_i = heating value per unit of clean coal from mine i,

γ_{kq} = heating value per unit of blended coal of qualtiy q for user k,

D_k = exogenously determined consumption at user k.

4. Each user was required to meet an aggregate limit on sulfur dioxide emissions.

$$\sum_i \sum_m \sigma_i U_{ikm} + \sum_i \sum_j \sum_m \theta_i V1_{ijkm} + \sum_n \sum_m \sum_q \ell_{kq} R_{nkmq}$$

$$\leq S_k = \pi_k D_k \tag{2.5}$$

where

σ_i = units of sulfur dioxide contained in one unit of raw coal from mine i,

θ_i = units of sulfur dioxide contained in one unit of clean coal from mine i,

ℓ_{kq} = units of sulfur dioxide contained in one unit of blended coal of quality q for user k,

S_k = maximum allowable sulfur dioxide emissions at user k,

π_k = maximum allowable emission standard measured as units of sulfur dioxide per unit of heating value.

5. The volume of coal blended at a blending plant cannot exceed the plant capacity.

$$\sum_i \sum_j \sum_m V2_{ijnm} + \sum_i \sum_m L_{inm} = \sum_k \sum_m \sum_q R_{nkmq} \leq BLC_n \tag{2.6}$$

where

BLC_n = blending plant capacity at site n.

6. The equivalent number of heating value units shipped into a blending plant must equal or exceed the equivalent number of heating value units shipped out of a blending plant.

$$\sum_i \sum_j \sum_m \Omega_i V2_{ijnm} + \sum_i \sum_m B_i L_{inm} \geq \sum_k \sum_m \sum_q \gamma_{kq} R_{nkmq} \tag{2.7}$$

7. The equivalent number of units of sulfur dioxide emissions shipped into a blending plant must be less than or equal to the equivalent number of units of sulfur dioxide emissions shipped out of the blending plant.

$$\sum_i \sum_j \sum_m \theta_i V2_{ijnm} + \sum_i \sum_m \sigma_i L_{inm} \leq \sum_k \sum_m \sum_q \Omega_{kq} R_{nkmq} \tag{2.8}$$

8. Additional nonnegative constraints are:

$$M_i,\ U_{ikm},\ V1_{ijkm},\ V2_{ijnm},\ Y_j,\ X_k,\ L_{inm},\ W_n,$$
$$R_{nkmq} \geq 0 \tag{2.9}$$

CHAPTER III. THE DATA

The data required by the model to minimize the cost of supplying Iowa's 1980 coal user consumption are as follows:

1. coal origins and their quality, quantity and price of the coal,
2. coal user locations, projected coal consumption, coal receiving cost by mode, and sulfur emission standards.
3. coal transportation rates by mode and size of shipment,
4. coal beneficiation locations and costs, and
5. coal blending locations, potential blends, and costs.

The first four data requirements were taken from an unpublished report on coal transportation done at Iowa State University (2).

Location, Quantity, and Quality of Coal Reserves

The future source of Iowa coal has been identified by geologists using overlaying maps showing potential coal-bearing strata and the thickness of overburden in an

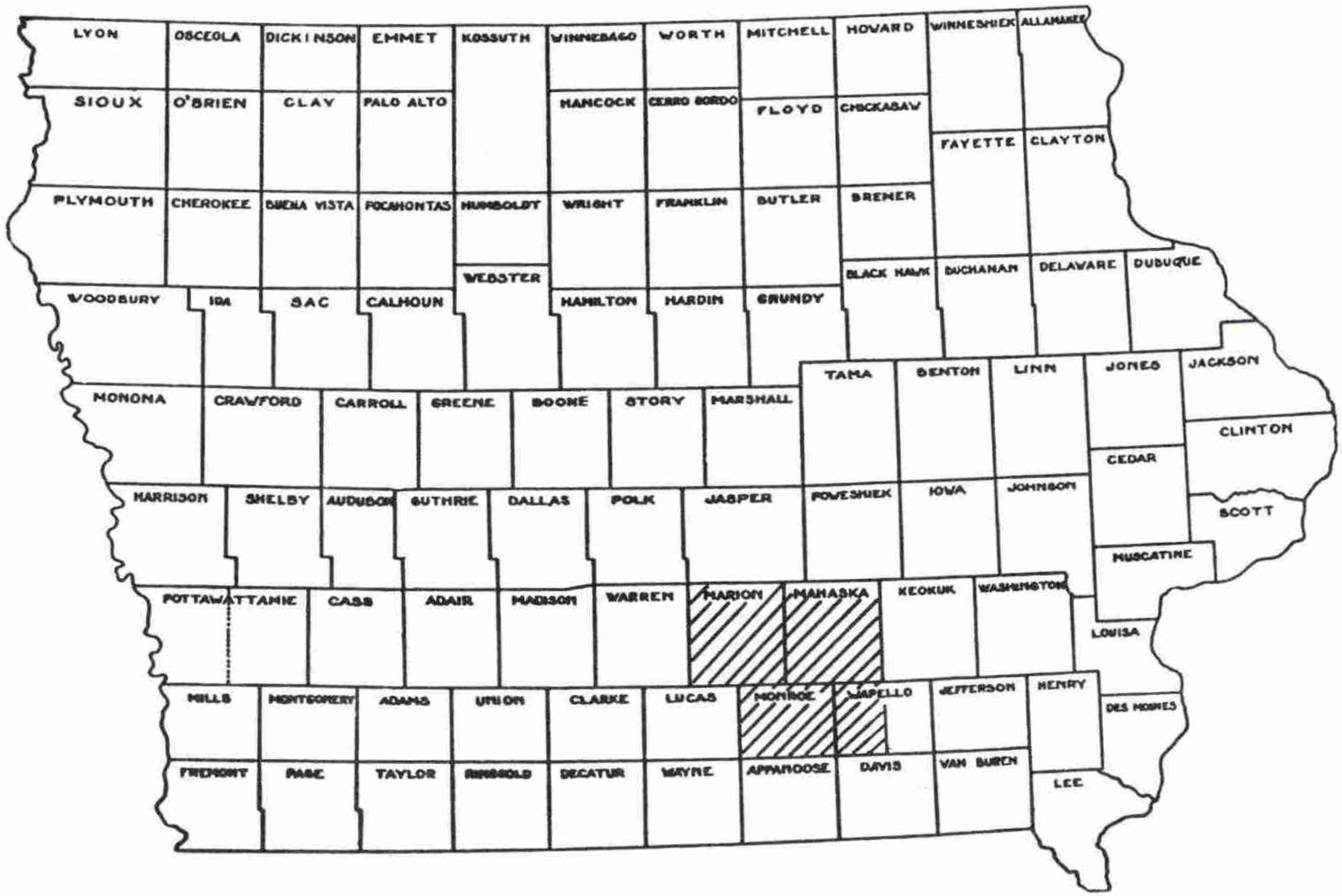
11-county area.[1] This process yields an area of three and one-half counties as the principal future source outlined in Map 3.1.

Available strippable coal reserves in this three and one-half county area were estimated from unpublished data of the Iowa Geological Survey (1). Available strippable coal reserves are defined as that coal-bearing strata with less than 50 feet of unconsolidated overburden, corrected for mining efficiency, that does not lie under towns, waterways, reservoirs, roads and flat agricultural land. Only coal with a 28-inch or thicker seam that is less than 150 feet below the surface entered into obtainable strip reserves. The estimated procedure was adopted in an unpublished study by Charles L. Eldridge (6).

The location, estimated quantity of obtainable strippable coal reserves, and the sulfur and Btu content in the coal area are presented in Map 3.2. The sulfur and Btu content based on core and channel samples were also estimated by the Iowa Geological Survey. Diagonally marked townships were not considered due to a high percent of noncoal-bearing strata, less than one million tons of obtainable strip mine reserves, or nonavailable survey maps.

---

[1] Lemish, John. Information on the location of potential coal-bearing strata and the thickness of unconsolidated material overburden over the potential coal-bearing strata. Personal communication. Department of Earth Science, Iowa State University, Ames, Iowa, February 1977.



Map 3.1. The selected Iowa coal producing area

	R21W	R20W	R19W	R18W	R17W	R16W	R15W	R14W
T77N	5.25 9794 3.59	5.25 9794 3.26	5.25 9794 1.55					
T76N	5.25 9794 1.83	5.25 9794 1.48	5.25 9794 3.82	5.25 9794 2.81		Mahaska	County	
T75N	5.25 9865 12.11	5.25 9865 13.12	5.33 9851 15.62	5.33 9851 3.11	5.83 10348 4.03	5.83 10348 2.37	5.60 10900 5.00	
T74N		Marion	County	5.33 9851 19.43	5.83 10348 7.68	5.83 10348 2.48		
T73N				3.24 10181 9.41	3.11 10798 4.23	3.11 10798 6.72	5.49 10294 1.08	
T72N					4.27 11549 1.11	4.27 11549 1.31	5.49 10294 4.47	
T71N			Monroe	County			Wapello	County

Top - Percent Sulfur

Middle - Btu per pound

Bottom - Millions of tons of coal

Map 3.2. Estimated obtainable strippable coal reserves, percent sulfur and Btu content per pound of coal located in selected townships of 3½ counties in Iowa, 1977 (2)

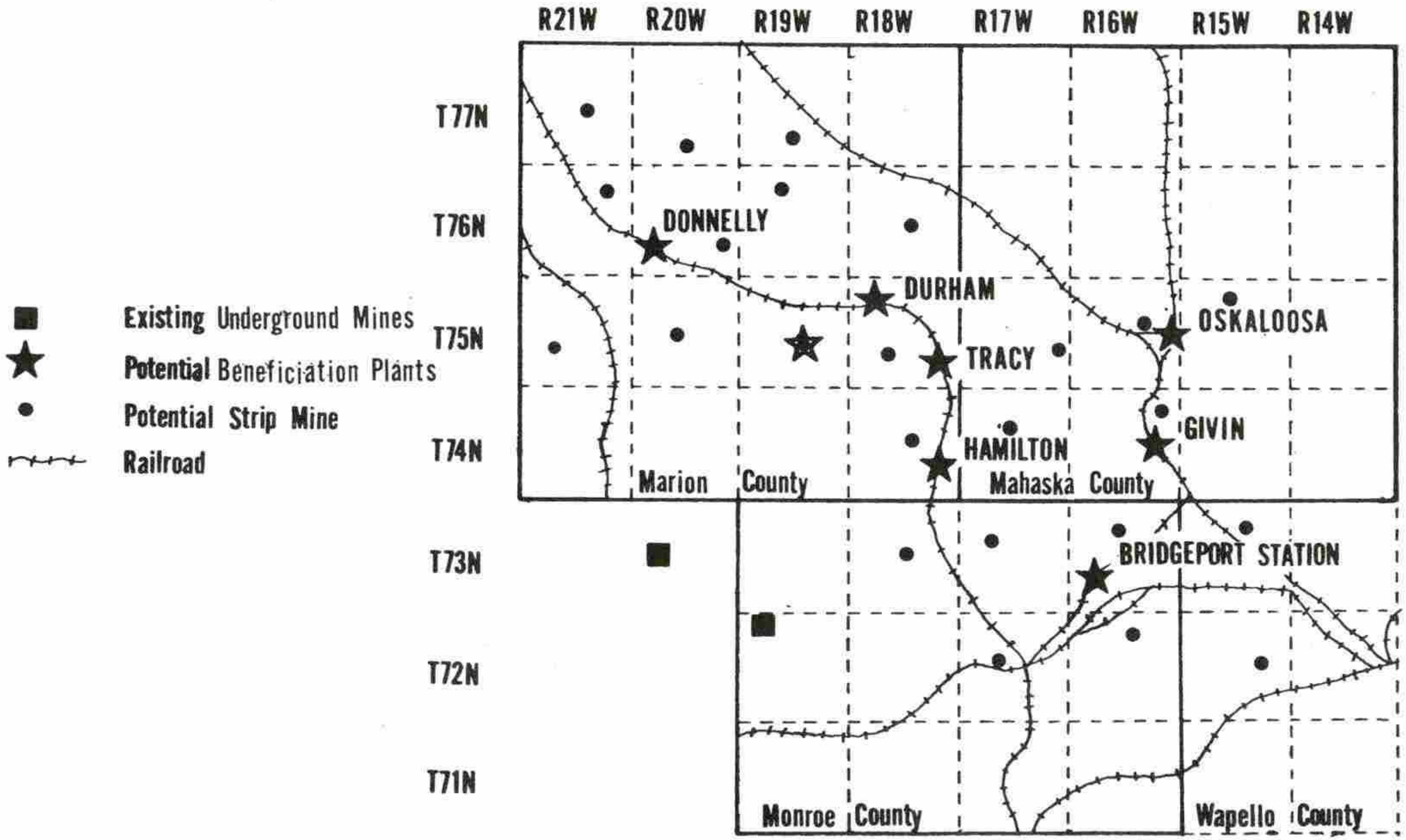
Potential mine sites were obtained by using the coal-bearing strata and overburden maps. Adjustments were made for cities, reservoirs, and rivers. Map 3.3 presents the locations of the coal mine origins.

Out-of-state coal mine origins were based on interviews with executives of utility companies and coal brokers who indicated present major origins of the coal used in Iowa. Sulfur and Btu content for non-Iowa coal mine origins were obtained from bonded coal bids submitted in early 1977 to Iowa State University, University of Iowa, and Ames Municipal Electric System. Table 3.1 presents selected origins and their sulfur and Btu content.

FOB Coal Prices

An input necessary to minimize the cost of supplying Iowa's 1980 coal consumption in the model developed in Chapter II is the FOB coal prices for the selected mine origins. The 1977 FOB coal prices with their respective Btu and sulfur content are presented in Table 3.1.

The FOB coal prices for non-Iowa mine origins were obtained from bonded coal bids submitted to Iowa State University, University of Iowa, and Ames Municipal Electric System in early 1977 for 62,500 to 100,000 tons of coal. No bids were submitted from Gillette, Wyoming since it basically serves large users. An advisory committee of



Map 3.3. Locations of potential strip mines and of existing underground mines in a 3½ county area in Iowa (2)

Table 3.1. FOB coal prices in dollars per ton and Btu and sulfur content by origin, 1977[a]

Origin	Required annual tons	Price (ton)	Btu (lb)	Sulfur (%)
Sheridan, Wyoming	-	$12.50	9,300	0.70
Gillette, Wyoming	500,000-1,500,000	7.50	8,100	0.48
	500,000-1,500,000[b]	7.00	8,100	0.48
	> 1,500,000[c]	6.25	8,100	0.48
Canton, Illinois	-	24.00	11,000	3.25
Sparta, Illinois	-	21.50	11,400	2.90
West Harrisburg, Ill.	-	22.65	12,455	1.97
Nortonville, Kentucky	-	21.50	11,400	2.50
Unionville, Missouri	-	17.65[d]	10,500	2.62
Iowa Mines				
Lovilla #4	-	15.01	9,772	3.04
Big Ben	-	12.43	9,628	5.32
Otley	-	13.48	8,929	6.26
Sutton	-	12.67	9,360	4.00
Star	-	11.08	10,338	7.65
Mich	-	12.15	9,387	5.81
ICO	-	15.65	9,676	3.82

[a]Bonded coal bids, discussions with utility and coal brokerage firm executives, and unpublished report, Pella Municipal Light and Power, Pella, Iowa.

[b]Shipments in 50- or 100-car trains.

[c]Shipments in 100-car trains.

[d]Cleaned coal.

utility and coal industry executives checked the bid prices for reasonableness. They suggested approximately $7.50 per ton for a minimum volume of 500,000 tons per year as a starting FOB bid price for Gillette, Wyoming coal. They also suggested that larger volumes and unit-train shipments would lower the Gillette FOB price as indicated in Table 3.1.

The FOB coal prices for Iowa mine origins were obtained from delivered prices to the Pella Municipal Light and Power Plant and to the Ames Municipal Electric System. Estimated transportation costs were then subtracted from the delivered prices to estimate the FOB prices at the mines. The estimated 1977 FOB Iowa strip mine prices at all potential mine sites were estimated by the following equation:

$$P = \alpha S^{\beta} \tag{3.1}$$

where

P = estimated price,

S = sulfur content in percent of weight,

α = constant, and

β = regression coefficient.

Price was assumed to be a function of sulfur (2,4) because of the additional costs in using higher sulfur coals incurred for emission control, for crushing the pyrite content, the reduction in beneficiation yield, and blending the high sulfur coal with low sulfur coal. Thus, price discounts would likely be required to induce users to burn higher sulfur coal.

The advisory committee suggested that the Iowa FOB mine prices at potential mine sites were too low to allow for the recovery of all costs if the Iowa coal mining industry were to open new mines. Therefore, the following procedure was used to adjust the 1977 Iowa and Missouri FOB mine prices to include estimated reclamation costs resulting from the Surface Mining Control and Reclamation Act of 1977 (13) and to allow for additional mining costs resulting from opening new mines.

An average mining cost including reclamation costs of \$17.33 per ton was estimated for a "typical" Iowa mine (2). An estimated Iowa reclamation cost of \$1.93 per ton was subtracted from the \$17.33 to yield an average mining cost net of reclamation of \$15.40 per ton (2). The difference between \$15.40 and \$13.48 (estimated average 1977 FOB Iowa strip mine price at all potential mine sites) reflects the estimated additional strip mine FOB price required to allow for the recovery of mine construction costs if the industry were to expand. This difference plus the \$1.93 reclamation cost was added to the Iowa strip mine prices estimated from Equation 3.1 to estimated the FOB Iowa strip mine prices at all potential mine sites.

Since the scale of operations in Missouri mines is larger than that of Iowa mines, an estimated cost savings of \$1.00 per ton was subtracted from the \$1.92 per ton Iowa price adjustment. The Missouri price adjustment was then converted to clean coal by dividing it by 0.77. The adjusted Iowa and Missouri prices are presented in Table 3.2. The estimated price of Iowa strip mine coal by locations is presented in Map 3.4 depicting the Iowa groups in Table 3.2.

The estimated additional mining costs resulting from the Surface Mining Control and Reclamation Act of 1977 are presented in Table 3.3 (13). The weighted reclamation costs were then added to the Wyoming, Illinois and Kentucky FOB prices and the adjusted FOB mine prices are presented in Table 3.2.

Iowa User Location and Projected Coal Consumption

A list of Iowa coal users was obtained from the Iowa Department of Environmental Quality. The list included only those firms that consumed over 1,000 tons in 1973. A questionnaire was mailed to each asking receiving capacities, recent coal usage, and expected coal usage in 1980 and 1985. Those who did not respond were contacted by telephone to obtain a 100 percent response. The list of users expecting to use coal in 1980 is presented in Table 3.4.

Reported coal consumption for 1973, 1974, and 1975 and projected consumption for 1980 and 1985 are presented in Table 3.5. Projected 1980 consumption is 16,132,492 tons by utility and industrial users. This is 267 percent greater than the reported 1975 consumption. In 1980 and 1985 utilities are expecting to consume about 85 percent of the total compared to

Table 3.2. Estimated FOB coal prices based on average Iowa mining and reclamation costs by coal origin (2)

Origin	Required annual tons	Sulfur (%)	Btu (lb)	FOB prices based on average Iowa mining costs
Sheridan, Wyoming	-	0.70	9,300	$12.65
Gillette, Wyoming	500,000-1,500,000	0.48	8,100	7.65
	500,000-1,500,000[a]	0.48	8,100	7.15
	1,500,000[b]	0.48	8,100	6.40
Canton, Illinois	-	3.25	11,000	24.70
Sparta, Illinois	-	2.90	11,400	22.20
West Harrisburg, Ill.	-	1.97	12,455	23.35
Nortonville, Kentucky	-	2.50	11,400	22.33
Unionville, Missouri	-	2.62	10,500	21.35[c]
Iowa underground mines				
Lovilla #4	-	2.75[d]	9,600	15.72
Big Ben	-	4.60[d]	10,225	13.53
Iowa strip mines				
Group I	-	5.25	9,794	16.87
Group II	-	5.33	9,851	16.81
Group III	-	5.83	10,348	16.47
Group IV	-	5.60	10,900	16.62
Group V	-	3.24	10,181	18.83
Group VI	-	3.11	10,798	19.01
Group VII	-	5.49	10,294	16.70
Group VIII	-	4.27	11,549	17.67

[a] Shipments in 50- or 100-car trains.

[b] Shipments in 100-car trains.

[c] Cleaned coal.

[d] Based on channel faced samples. These samples indicated 9,600 and 10,225 Btu per pound for Lovilla #4 and Big Ben Coal respectively.

	R21W	R20W	R19W	R18W	R17W	R16W	R15W	R14W
T77N	16.87	16.87	16.87					
T76N	16.87	16.87	16.87	16.87		Mahaska	County	
T75N	16.87	16.87	16.81	16.81	16.47	16.47	16.62	
T74N		Marion	County	16.81	16.47	16.47		
T73N				18.83	19.01	19.01	16.70	
T72N					17.67	17.67	16.70	
T71N			Monroe	County			Wapello	County

Map 3.4. Estimated FOB prices of Iowa strip mine coal based on average Iowa mining costs in dollars per ton (2)

The estimated additional mining costs resulting from the Surface Mining Control and Reclamation Act of 1977 are presented in Table 3.3 (13). The weighted reclamation costs were then added to the Wyoming, Illinois and Kentucky FOB prices and the adjusted FOB mine prices are presented in Table 3.2.

Iowa User Location and Projected Coal Consumption

A list of Iowa coal users was obtained from the Iowa Department of Environmental Quality. The list included only those firms that consumed over 1,000 tons in 1973. A questionnaire was mailed to each asking receiving capacities, recent coal usage, and expected coal usage in 1980 and 1985. Those who did not respond were contacted by telephone to obtain a 100 percent response. The list of users expecting to use coal in 1980 is presented in Table 3.4.

Reported coal consumption for 1973, 1974, and 1975 and projected consumption for 1980 and 1985 are presented in Table 3.5. Projected 1980 consumption is 16,132,492 tons by utility and industrial users. This is 267 percent greater than the reported 1975 consumption. In 1980 and 1985 utilities are expecting to consume about 85 percent of the total compared to 80 percent in 1973, 1974, and 1975. The projected 1985 coal consumption by utilities and industrial users is 114 percent

Table 3.3. Estimated reclamation costs resulting from the surface mining control and reclamation act of 1977 by state in dollars per ton of raw coal (2)

Origin	Weighted reclamation cost per ton[a]
Wyoming	\$0.15
Illinois	0.70
Western Kentucky	0.83
Iowa	1.93[b]
Missouri	1.93

[a]Estimated reclamation cost weighted by the percentage of coal production that is strip mined.

[b]Applied only to potential strip mine coal.

Table 3.4. Names and locations of coal users included in this analysis, Iowa[a]

Location	Name
Ames	Ames Municipal Electric System
Ames	Iowa State University
Bettendorf	Iowa-Illinois Gas & Electric Company
Bettendorf	J. I. Case Co.
Boone	Iowa Electric Light & Power Company
Bridgeport Station	Iowa Southern Utilities Company
Buffalo	Martin Marietta Cement, Midwest Division
Burlington	Iowa Southern Utilities Company
Cedar Falls	Cedar Falls Utilities
Cedar Falls	University of Northern Iowa
Cedar Rapids	Iowa Electric Light & Power Co., Prairie Creek Station
Cedar Rapids	Iowa Electric Light & Power Co., 6th Street Station

[a]Iowa Department of Environmental Quality.

Table 3.4 (Continued)

Location	Name
Cedar Rapids	Wilson Foods Corporation
Chillicothe	Iowa Southern Utilities Company
Clinton	Clinton Corn Processing Co.
Clinton	E. I. DuPont de Nemours & Co.
Clinton	Interstate Power Company
Council Bluffs	Iowa Power & Light Company
Davenport	Linwood Stone Products Co., Inc.
Davenport	Oscar Mayer & Company
Davenport	Ralston Purina Company
Des Moines	Iowa Power & Light Company
Dubuque	The Celotex Corporation
Dubuque	Interstate Power Company
Dubuque	John Deere Dubuque Tractor Works
Humboldt	Corn Belt Power Cooperative
Iowa City	University of Iowa
Iowa Falls	Iowa Electric Light & Power Co.
Keokuk	The Hubinger Company
Lansing	Interstate Power Company
Marshalltown	Iowa Electric Light & Power Company
Mason City	Lehigh Portland Cement Company
Mason City	Northwestern States Portland Cement Co.
Middletown	Iowa Army Ammunition Plant
Montpelier	Eastern Iowa Light & Power Cooperative
Muscatine	Grain Processing Corporation
Muscatine	Muscatine Power & Water
Pella	Pella Municipal Light Plant
Sergeant Bluff	Iowa Public Service Company
Spencer	Corn Belt Power Cooperative
Spencer	Spencer Municipal Utilities
Waterloo	Iowa Public Service Company
Waterloo	John Deere Waterloo Tractor Works
Waterloo	The Rath Packing Company
West Des Moines	Marquette Cement Manufacturing Company
West Des Moines	Penn-Dixie Cement Corporation

Table 3.5. Reported tons of coal consumed by Iowa users in 1973, 1974, 1975 and projected 1980 and 1985[a]

Year	Type of User		
	Utility	Industrial	Total
1973	5,278,192	1,309,329	6,587,521
1974	4,744,384	1,150,419	5,894,803
1975	4,997,157	1,342,107	6,339,264
1980	13,751,172	2,381,320	16,132,492
1985	15,856,659	2,588,290	18,444,949

[a]Questionnaire.

80 percent in 1973, 1974, and 1975. The projected 1985 coal consumption by utilities and industrial users is 114 percent greater than 1980.

Coal Receiving Cost

Coal receiving costs are composed of the variable cost to receive and unload from trucks, rail, and barges and to transfer coal to a live storage pile and an additional investment cost required to upgrade existing facility equipment to handle larger shipment sizes. The variable receiving costs differ by mode and sizes of shipment; and include labor, fuel, power, and maintenance of equipment. Table 3.6 presents the estimated variable costs obtained from industry executives.

Only the additional investment costs required to upgrade existing facilities were included. The costs associated with

Table 3.6. Estimated variable cost per ton of receiving, unloading, and transferring coal to live storage by mode of transport (Iowa, 1977)[a]

Mode of transport	Variable cost per ton
Rail	
Single-car shipment	$0.35
15-car shipment	0.25
50-car shipment	0.20
100-car shipment	0.11
Truck	0.05
Barge	0.25-0.40[b]

[a]Utility company executives.

[b]Depends on location.

the existing facilities were excluded since these costs are considered "sunk". Data on existing facilities were obtained for each coal user by the questionnaire and telephone calls. Total facility requirements to handle a given rail shipment size and estimated unit cost of the equipment were obtained from industry engineers. Coal users were allowed to upgrade to the next larger shipment size. For example, single-car receivers were upgraded to 15-car receivers. No upgrading was applied to existing 100-car receivers. The procedure used to estimate the additional investment costs from upgrading was to subtract the amount of each usable existing equipment from the total facility requirements. The estimated unit costs were applied to the additional requirements to estimate the additional investment costs. Tables 3.7, 3.8 and 3.9 present individual cost users with their total and annual investment costs grouped by the next level of receiving capacity.

The annual costs were obtained by converting the estimated total cost in the equation (11):

$$\text{A.E.C.} = P\{i(1+i)^n((1+i)^n-1)^{-1}\}-S\{i((1+i)^n-1)^{-1}\} \quad (3.2)$$

where

A.E.C. = annual equivalent cost,

P = purchase price,

S = salvage value,

n = useful life in years, and

i = interest rate.

Thirteen coal users were not upgraded to the next larger receiving capacity. If the expected 1980 tons of coal to be used would provide for less than one shipment per month of the next larger shipment size or the user historically received all of its coal by either truck and/or barge, the user was not given the opportunity to upgrade. While these estimated

Table 3.7. Estimated total and annual cost of upgrading receiving, unloading and conveying facilities to handle 15-car rail shipments of coal, by coal user, 1977 cost levels (2)

Location	Coal user	Estimated upgrading cost Total	Estimated upgrading cost Annual[a]
Boone	Iowa Electric Light & Power Company	$519,838	$61,950
Cedar Falls	University of Northern Iowa	397,800	56,350
Cedar Rapids	Wilson Foods Corporation	485,213	55,738
Clinton	E. I. Du Pont de Nemours & Co.	323,038	37,147
Davenport	Oscar Mayer & Company	373,838	42,326
Dubuque	John Deere Dubuque Tractor Works	447,538	51,849
Humboldt	Corn Belt Power Cooperative	397,800	46,725
Iowa City	University of Iowa	351,088	40,043
Middletown	Iowa Army Ammunition Plant	0	0
Muscatine	Grain Processing Corporation	436,538	50,714
Waterloo	John Deere Waterloo Tractor Works	345,038	41,418
Waterloo	The Rath Packing Company	537,788	66,360
West Des Moines	Marquette Cement Manufacturing Company	529,538	63,509
West Des Moines	Penn-Dixie Cement Corporation	502,600	61,375

[a]10% interest rate.

Table 3.8. Estimated total and annual cost of upgrading receiving, unloading and conveying facilities to handle 50-car rail shipments of coal, by coal user, 1977 cost levels (2)

Location	Coal user	Estimated upgrading cost: Total	Estimated upgrading cost: Annual[a]
Ames	Ames Municipal Electric System	$1,094,125	$130,463
Ames	Iowa State University	1,143,125	135,812
Bettendorf	Iowa-Illinois Gas & Electric Company	785,000	92,206
Burlington	Iowa Southern Utilities Company	455,125	50,374
Cedar Falls	Cedar Falls Municipal Utility	1,224,125	147,734
Cedar Rapids	Iowa Electric Light & Power Co., 6th Street Station	1,238,225	148,499
Cedar Rapids	Iowa Electric Light & Power Co., Prairie Creek Station	785,000	92,206
Clinton	Clinton Corn Processing Company	1,057,625	126,847
Clinton	Interstate Power Company	1,241,425	148,187
Marshalltown	Iowa Electric Light & Power Company	941,625	109,012
Mason City	Lehigh Portland Cement Company	991,625	118,033
Mason City	Northwestern States Portland Cement Co.	774,125	92,557
Muscatine	Muscatine Power & Water	1,110,625	132,167
Spencer	Corn Belt Power Cooperative	705,375	86,932
Waterloo	Iowa Public Service Company	1,165,125	132,987

[a] 10% interest rate.

Table 3.9. Estimated total and annual cost of upgrading receiving, unloading and conveying facilities to handle 100-car rail shipments of coal, by coal user, 1977 cost levels (2)

Location	Coal user	Estimated upgrading cost	
		Total	Annual[a]
Chillicothe	Iowa Southern Utilities Company	$ 0	$ 0
Council Bluffs	Iowa Power & Light Company	0	0
Des Moines	Iowa Power & Light Company	5,204,000	604,753
Sergeant Bluff	Iowa Public Service Company	0	0

[a]10% interest rate.

costs were obtained from data provided from industry engineers, the costs should be used as only approximations to the actual costs that would be obtained by a detailed engineering analysis.

Sulfur Dioxide Emission Standards

One of the more important problems in burning coal is the amount of sulfur dioxide that is emitted into the air. Due to this pollution problem, federal standards on emission have been imposed. However, both local and state governments are allowed to adopt more restrictive standards than the federal standard with the applicable local standard the most restrictive. The current standards as of July 1, 1977 and the standards used in this study are presented in Table 3.10. The most restrictive standard applies to boilers built on or after August 17, 1971 that consume more than 250 million Btu per hour.

Rail Rates

Ex Parte 336 rail rates for out-of-state mines were obtained from railroad companies. The intrastate rates were obtained from Western Truck Line Freight Tariff 160-S, Supplement 149, June 15, 1977 and adjusted according to correspondence from the Western Trunk Line Committee to the

Table 3.10. Applicable sulfur dioxide emission standards and standards used in this analysis in pounds of sulfur dioxide per million Btu by county and by age and size of boiler (Iowa, July 1, 1977)

Age of boiler	Size of boiler	County	Pounds of SO_2 per million Btu: Current standard[a]	Pounds of SO_2 per million Btu: Standard used in this analysis
Boilers built after August 17, 1971	$\geq$ 250,000,000 Btu/hr	All counties	1.2	1.2
	$\leq$ 250,000,000 Btu/hr	All counties	6.0	6.0
Boilers built before August 17, 1971	All sizes	Polk	5.0[b,c]	5.0
	All sizes	Linn	5.0[c,d]	5.0
	All sizes	Dubuque	6.0[c]	6.0
	All sizes	Jackson	6.0[c]	6.0
	All sizes	Clinton	6.0[c]	6.0
	All sizes	Scott	6.0[c]	6.0
	All sizes	Muscatine	6.0[c]	6.0
	All sizes	Louisa	6.0[c]	6.0
	All sizes	Des Moines	6.0[c]	6.0
	All sizes	Lee	6.0[c]	6.0
	All sizes	Black Hawk	6.0[c]	6.0
	$\geq$ 500,000,000 But/hr	All other counties	8.0[c]	8.0
	$\leq$ 500,000,000 But/hr	All other counties	12.0[c]	8.0

[a]Unless otherwise specified, Iowa Administrative Code (12).

[b]Polk County Local Board of Health, Rules and Regulations, Chapter 5, Air Pollution Control (10).

[c]Not approved as part of the Iowa State Implementation Plan.

[d]Linn County Regulation Number 1-72, Air Pollution (9).

Iowa Department of Transportation, June 28, 1977. Rail rates were estimated for 15-car, 50-car, and 100-car rates for those mines and users which rates did not exist. The procedure for estimating rail rates was presented in a study done by Baumel, Drinka, and Miller (2). Table 3.11 presents rates from selected non-Iowa mine origins and one Iowa mine origin to selected users. In Table 3.11, the single-car rates are basically actual rates while the 15-car, 50-car, and 100-car unit train rail rates are estimated. The 100-car rate was not estimated for Iowa mine origins assuming that Iowa coal would be used by small users or in small quantities by large users due to their emissions standards.

Table 3.12 presents estimated 100-car rates from selected non-Iowa origins and estimated 50-car rates from one Iowa beneficiation plant to the eight selected blending plants. The rates from non-Iowa origins were restricted to 100-car unit trains to allow the blending plant the opportunity of economies of scale in its operation. The Iowa beneficiation plants were limited to 50-car rates due to the capacity. Also, Unionville, Missouri was restricted to 50-car rate because this coal is consumed by smaller users.

Table 3.13 presents rates from the selected Iowa blenders to selected Iowa users. These rates for blenders to users were based on estimated rail costs. Blenders were not allowed

Table 3.11. Selected rates of coal shipments by mode from selected origins to selected Iowa users at Ex Parte 336 rate levels and estimated rates at mid-1977 price levels in dollars per ton (2)

Iowa users		Origin: Gillette, Wyoming	Sparta, Illinois	West Harrisburg, Illinois	Unionville, Missouri[a]	Oskaloosa, Iowa
Sergeant Bluff	Sgl-car	15.05	12.52	12.76	9.49	7.67
	15-car	11.26	10.83	11.25	9.71	6.15
	50-car	10.10	10.68	11.13	9.28	5.58
	100-car	7.73	8.35	8.70	–[b]	–[b]
Ames	Sgl-car	17.05	10.34	10.58	7.55	5.06
	15-car	12.22	8.76	9.19	6.93	3.70
	50-car	11.05	8.47	8.92	6.31	2.99
	100-car	8.55	6.55	6.91	–[b]	–[b]
Dubuque	Sgl-car	18.01[c]	8.45	8.79	8.84	6.76
	15-car	14.25	6.96	7.14	7.86	5.44
	50-car	13.04	6.51	6.71	7.28	4.84
	100-car	10.17	4.92	5.07	–[b]	–[b]
Burlington	Sgl-car	16.32	7.56	8.39	7.00	5.69
	15-car	15.52	6.65	7.08	6.49	4.67
	50-car	12.52	6.20	6.66	5.85	4.03
	100-car	9.20	4.72	5.07	–[b]	–[b]

[a]Estimated rail rates from Centerville, Iowa plus estimated trucking cost from Unionville to Centerville plus transfer cost from truck to rail at Centerville.

[b]100-car rail rates not applicable for Missouri and Iowa origins.

[c]Estimated rail rates.

Table 3.12. Selected estimated rates of 100-car coal shipments by rail from selected origins and beneficiation plant to selected Iowa blenders at Ex Parte 336 rate levels in dollars per ton

Iowa blenders	Origin					Beneficiator
	Gillette, Wyoming	Sparta, Illinois	West Harrisburg, Illinois	Nortonville, Kentucky	Unionville, Missouri[a]	Oskaloosa, Iowa[b]
Marshalltown	8.81	6.21	6.58	7.49	6.25	2.65
Des Moines	8.56	6.30	6.69	7.61	5.10	3.37
Chillicothe	8.37	5.47	5.82	6.74	4.17	3.37
Cedar Rapids	9.60	5.43	5.80	6.70	5.65	3.38
Muscatine	10.16	4.94	5.33	6.26	5.27	4.00
Oskaloosa	9.07	6.39	6.76	7.66	5.07	0.00
Donnelly	9.41	5.86	6.23	7.15	5.48	2.90
Bridgeport Station	8.92	6.24	6.61	7.51	5.02	1.65

[a]Estimated 50-car rate from Centerville, Iowa plus $1.99 estimated trucking cost from Unionville, Missouri to Centerville and truck to rail transfer costs.

[b]Estimated 50-car rates.

Table 3.13. Selected rates of coal shipments by mode from selected Iowa blenders to selected Iowa coal users at Ex Parte 336 rate levels in dollars per ton

Iowa users	Mode	Blenders: Marshalltown	Des Moines	Chillicothe	Cedar Rapids	Muscatine	Oskaloosa
Spencer	Sgl-car	6.40	6.30	7.10	6.86	7.55	7.05
	15-car	5.51	4.71	6.25	6.03	6.90	6.05
	50-car	4.93	4.07	5.71	5.49	6.40	5.49
Waterloo	Sgl-car	3.83	5.49	5.77	3.92	5.95	5.43
	15-car	3.40	3.97	4.90	3.55	4.42	3.85
	50-car	2.69	3.29	4.29	2.85	3.77	3.15
Ames	Sgl-car	3.45	3.59	5.49	5.43	6.64	5.06
	15-car	3.25	3.30	4.74	4.04	5.58	3.70
	50-car	2.54	2.58	4.13	3.37	5.01	2.99
Clinton	Sgl-car	6.30	6.86	6.40	4.86	4.18	6.58
	15-car	4.57	5.16	4.59	3.58	3.33	5.26
	50-car	3.92	4.56	3.96	2.87	2.60	4.65
Burlington	Sgl-car	6.40	6.40	4.98	5.31	4.18	5.68
	15-car	5.42	5.35	4.48	3.77	3.38	4.67
	50-car	4.84	4.78	3.85	3.07	2.65	4.03

the 100-car rates. Since most of the Iowa users have a 50-car receiving capacity or less, the blending plant was restricted to 50 cars at one time. Also, the users who do have a 100-car receiving capacity are relatively new plants restricting them to a very low sulfur dioxide emissions standard.

Trucking Rates

Estimated trucking costs were summarized by a regression analysis of the following form:

$$C_t = \alpha_t + \beta_t m \qquad (3.3)$$

where for type of haul t

C_t = total cost in dollars per ton,

α_t = fixed cost in dollars per ton,

β_t = variable cost in dollars per ton-mile, and

m = one-way miles.

The constant "α" is the fixed cost of providing the vehicle and the transfer time to load and unload. The coefficient "β" is the cost of hauling one ton one additional mile. The estimated trucking cost functions by type of haul are presented in Table 3.14. Estimated trucking costs were increased by 15 percent to approximate trucking rates for coal by the expression:

$$R_t = 1.15\ C_t \qquad (3.4)$$

Table 3.14. Trucking cost functions by type of haul, type of vehicle and distance hauled (6)

Type of haul	Type of vehicle	One-way miles hauled	Dollars per ton	
			α	β
Mine to beneficiation plant	Tandem axle dump	0.25-25	$0.17432	$0.05776
Refuse from beneficiation plant to mine	Tandem axle dump	0.25-25	0.13681	0.04195
Beneficiation plant, underground mine, or blending plant to users; strip mine to blending plant	Tandem axle dump truck with pup trailer	5-19.99	0.36681	0.04141
		20-74.99	0.37112	0.04114
		75-200	0.74342	0.03603

where for type of haul t

R_t = estimated trucking rate in dollars per ton.

Table 3.15 presents estimated trucking rates for selected Iowa mines and selected beneficiation plants to selected Iowa blending plants. These rates were based on the trucking cost function for a tandem axle dump truck with a pup trailer presented in Table 3.14.

Table 3.16 presents estimated trucking rates from selected Iowa blenders to selected Iowa users. These rates were based on the trucking cost function in Table 3.14 for a tandem axle dump truck with a pup trailer.

Rail-Barge Transportation Rates

The rail-barge transportation rates are presented in Table 3.17. The rail-barge rates include rail from mine to barge loading facilities, loading the coal on barges, and barging the coal to a user. The rail-barge movement is an important mode of transportation for the coal users on the Mississippi River. In 1975, barge shipments accounted for 19 percent of the coal received by Iowa users. The electric utility at Lansing is currently receiving Wyoming coal by rail-barge movement. A 100-car unit train is shipped from Gillette, Wyoming to Alton, Illinois where the coal is

Table 3.15. Estimated trucking rates from selected Iowa mines and selected beneficiation plants to selected Iowa blenders at mid-1977 prices in dollars per ton

Selected Iowa origins	Iowa blenders					
	Marshalltown	Des Moines	Chillicothe	Cedar Rapids	Muscatine	Oskaloosa
Mines[a]						
T73N-R18W	3.45	3.67	1.44	6.01	5.79	1.70
T76N-R19W	2.98	2.58	2.53	5.60	5.37	1.78
T72N-R15W	4.55	4.74	0.60	5.46	5.24	1.36
T74N-R16W	3.71	3.93	1.18	5.14	4.92	0.71
Processors						
1 Bridgeport Station	3.98	4.17	0.90	5.65	5.42	1.29
2 Oskaloosa	3.71	3.93	1.18	4.89	4.67	0.00
3 Givin	3.77	3.97	1.12	5.13	4.91	0.69
7 Hamilton	3.35	3.56	1.55	5.80	5.57	1.46

[a]Location of these mines are depicted in Map 3.3.

Table 3.16. Estimated trucking rates from selected Iowa blenders to selected Iowa users at mid-1977 prices in dollars per ton

Iowa blenders	Iowa users					
	Humboldt	Waterloo	Ames	Clinton	Davenport	Burlington
Marshalltown	5.45	3.31	2.18	7.34	7.34	8.35
Des Moines	5.27	6.18	1.87	8.89	7.53	8.54
Chillicothe	9.00	5.35	5.76	8.06	6.32	4.81
Cedar Rapids	8.38	3.71	5.14	4.42	4.42	5.43
Muscatine	11.30	6.66	8.06	3.81	1.82	2.51
Oskaloosa	8.33	4.92	5.10	7.63	5.89	5.47
Donnelly	6.89	5.96	3.63	8.68	6.94	6.91
Bridgeport Station	8.58	5.67	5.35	8.38	6.64	5.23

Table 3.17. Estimated rail-barge rates and transfer costs from rail to barge for selected coal origins and Iowa destinations in dollars per ton, 1977 (2)[a]

Destination	Coal origins to barge loading points		
	Sparta to Kellogg, Ill.	West Harrisburg to E. St. Louis, Ill.	Nortonville to Grand Rivers, Ky.[b]
Keokuk	$4.05	$5.50	$6.50
Muscatine	4.35	5.80	6.29
Montpelier	4.35	5.80	6.31
Davenport	4.35	5.80	6.24
Clinton	4.17	5.62	5.96
Dubuque	4.42	5.87	6.24
Lansing	4.67	6.12	6.47

[a]Rail rates for single-car shipments at Ex Parte 336 rate level.

[b]Based on estimated barge rates.

transferred to a barge for shipment to Lansing.

Coal Beneficiation Location and Costs

Coal beneficiation location and costs were developed in an unpublished study (6). Seven potential coal beneficiation locations with rail service and one without rail service were selected on the basis of proximity to potential coal mines and availability of land to build a plant. Table 3.18 presents the additional annual cost of upgrading the present siding at each of the seven locations to at least 5800 feet of siding to handle 50 rail cars, each car having a 100-ton capacity.

The beneficiation plant was based on an actual proposed construction package in Iowa. The plant, rated at 250 tons per hour raw coal feed rate, was assumed to operate 14 hours per day at five days a week for 45 weeks. Annual consumption was estimated to be 840,000 tons of raw coal. The beneficiation process yields 77 percent clean coal with 23 percent refuse or 646,800 tons of clean coal.

The estimated initial investment cost of a coal beneficiation plant is $2,558,127 or $325,413 annually. The investment includes the processing equipment, load-out facility, front-end loader, water impoundment, site improvement, miscellaneous settling ponds, supplemental water

Table 3.18. Estimated annual cost of additional siding at seven potential Iowa coal beneficiation locations, 1977 (2)

Potential Iowa coal beneficiation location	Annual cost additional siding
Givin	$34,636
Oskaloosa	32,523
Bridgeport Station	23,952
Donnelly	21,470
Durham	33,994
Tracy	31,549
Hamilton	38,552

well, utility extension and sub-station upgrading, and land.

Other costs are incurred that do not change with the volume of processed coal. These costs include maintenance and repairs, insurance and property tax, general manager's and supervisor's salary, office expense, and miscellaneous expenditures. These fixed costs total $305,444 annually. Therefore, total annual fixed costs are $676,857 ($326,413 plus $305,444) plus the annual additional rail siding cost.

The estimated total variable cost is $0.819 per ton of beneficiated coal. Variable costs include electricity, supplies, labor, analysis of coal, tires and fuel to run the front-end loader, and profit.

Coal Blending

Locations

Eight Iowa sites were selected as potential blending locations. The sites selected are as follows:

Cedar Rapids
Chillicothe
Des Moines
Marshalltown
Muscatine
Bridgeport Station
Donnelly
Oskaloosa

Five of the potential blending sites were selected to be located at existing electric utility plants. These plants were selected because of the following reasons:

1. The utilities each use large quantities of coal which if blended there, would require no transshipment.
2. The utility plants are located relatively close to other coal users.
3. The utility plants would incurr relatively low costs to upgrade their facilities to blend coal.
4. The utility plants are located relatively close to potential Iowa coal mines.

Coal beneficiation sites were selected by a previous analyses (2).

Investment costs

The estimated cost of upgrading utility plants and coal beneficiation plants to blenders includes the additional investment in equipment to receive, unload, and transfer coal from a 100-car unit train to a live storage pile and the investment in equipment to blend and load-out coal. The additional investment to handle a 100-car unit train and to blend coal was obtained by subtracting the existing useable equipment from the total facility requirements. The capacity of a blend plant was assumed to be 3.2 million tons annually. The total facility requirements and the estimated total and annual costs for a blending plant obtained from data provided by industry executives are presented in Table 3.19. The total costs were converted to annual costs by Equation 3.2.

A loop track is needed to handle unit trains within the unloading time specified in most freight tariffs. The length of a 100-car unit train is about 5250 feet which would require a loop track of 8700 feet. The estimated cost of installing the loop track to handle 100 ton hopper cars which includes new rail at 115 pounds per yard, ballast, ties, and grading was \$100 per foot. Salvage value of the loop track at the end of 35 years was estimated to be \$217.50 per ton of rail and \$4.00 per tie for 3000 ties per mile. Land requirements for the loop track are 100 acres. A price of \$2000 per acre was assumed for this 100 acres at coal beneficiation plants

Table 3.19. Estimated total and annual costs to receive 100-car unit trains, blend, and load-out coal in 1977 prices

Facility Requirements	Useful life in years	Estimated upgrading cost Total	Estimated upgrading cost Annual[a]
Rail	35	$ 870,000	$ 90,210
Land		200,000	20,000
Underground hopper	20	1,500,000	176,190
Car shaker	20	44,800	5,262
Thaw shed	20	390,000	45,809
Conveyors to live storage	20	1,280,000	150,348
2-D9 Caterpillar tractors with blade	10	250,000	40,688
Stacker-reclaimer	20	1,680,000	197,333
Foundation for stacker-reclaimer	20	900,000	105,714
Dust system	20	381,000	44,752
Reclaim hopper	20	260,000	39,540
Conveyors to holding silo	20	405,000	47,571
Samplers and belt scales	20	418,000	49,098
Holding silo	20	300,000	35,238
Hopper over tracks	20	250,000	29,365
TOTAL		$9,128,800	$1,068,118

[a] 10% interest rate.

which are located in rural areas. A price of $10,000 per acre was assumed for electric utilities. Because unit train tariffs require the coal trains to be unloaded in no more than four hours, it was assumed that the railroad locomotives will remain with the train. Therefore, no switch engines are required. An underground unloading hopper is used to dump the coal from rail cars. The unloading hopper including the equipment and installation was estimated to cost $1.5 million. In some cases, these selected blending locations already have an underground unloading hopper. Therefore, an estimated cost of $25,000 for reworking the hopper to handle the increased volume was substituted for those having a useable hopper. The salvage value of the underground hopper was assumed to be equal to the dismantling cost at the end of a 20 year life.

A car shaker that fits on the car top plus a three-car length thaw shed is needed to loosen coal frozen around the edges of the cars. It was assumed that the salvage value of the shaker and thaw shed at the end of 20 years equals the cost of dismantling.

Sixteen hundred feet of conveyors was assumed to be required to transfer the coal from the underground unloading hopper to the live coal storage area. The cost of installing the conveyors was estimated to be $800 per foot. Salvage value at the end of 20 years was assumed equal to the cost of dismantling. Since the unit train tariffs specify a four hour unloading time, the conveyors were assumed to have a capacity of 3300 tons per hour. This permits a 100-car unit train of 10,000 tons to unload in 3.3 hours and still provide some additional time for unexpected problems. A stacker-reclaimer, which travels on a track above the live storage area, stockpiles the coal in several piles. The stacker-reclaimer was assumed to have a capacity of 3300 tons per hour. Salvage value on the stacker-reclaimer at the end of 20 years was assumed to equal the cost of dismantling. Two D-9 Caterpillar tractors with capacity to move 600 tons of coal per hour 400 feet are used to assist in stockpiling and reclaiming the coal. The salvage value on the Caterpillar tractors at the end of 10 years was estimated to be 10 percent of the original purchase price.

A dust control system which collects coal polluting dust during the unloading process is required for environmental protection. The salvage value at the end of 20 years was assumed to equal the cost of removal on the dust collecting equipment.

To achieve various blend types, a reclaim hopper with a variable feeder is used. Nine hundred additional feet of conveyors rated at 600 tons per hour were assumed to carry the blended coal to the loading silo and hopper. The estimated installed cost of the conveyors is $450 per foot. Two samplers and three belt scales are required to achieve correct blends. A 600-ton capacity silo located over the hopper helps regulate the coal flow evenly to the loading hopper. The hopper is located over the loop track modificated to load either rail cars or trucks. The blending setup is positioned within the loop track thus conserving the amount of land and rail siding needed. The estimated salvage value of the blending equipment at the end of 20 years was assumed to be equal to the dismantling cost. The total installed cost of blending equipment was estimated to be $1.6 million. Using Equation 3.2, the annual cost was estimated to be $191,812.

The estimated cost of upgrading each selected location to a blending plant is presented in Table 3.20. Total additional upgrading costs were converted to annual costs by Equation 3.2. The total costs range between $7.0 million and $7.5 million while the annual costs are approximately $850,000. The total cost for upgrading Chillicothe to a blending plant is only $1.6 million because the facility at Chillicothe already has the equipment to receive a 100-car unit train.

Table 3.20. Estimated additional total and annual cost of upgrading to a blending facility by location in 1977 prices

Location	Name	Estimated additional upgrading cost	
		Total	Annual[a]
Bridgeport Station	Coal Processor	$7,481,300	$881,754
Cedar Rapids	Iowa Electric Light & Power Company, Prairie Creek Station	7,241,500	836,363
Chillicothe	Iowa Southern Utilities Company	1,633,000	191,812
Des Moines	Iowa Power and Light	6,837,000	796,565
Donnelly	Coal Processor	7,617,550	897,477
Marshalltown	Iowa Electric Light & Power Company	7,236,500	843,297
Muscatine	Muscatine Power & Water	7,246,700	849,135
Oskaloosa	Coal Processor	7,609,800	895,695

[a]10% interest rate.

Variable operating costs

The variable cost of blending coal obtained from data provided by industry executives was estimated to be 82.5 cents per ton. This includes 25 cents per ton for labor, power, and equipment repairs to reclaim and blend the coal and load it into a rail car or truck, 7.5 cents per ton from physical weight loss, and 50 cents per ton profit.

Potential Coal Blends

Potential coal blend types must be specified for the model because the transportation activities are a function of dollars per ton and the users demand is a function of heating value. Therefore, the model requires an input-output coefficient relating transportation cost in dollars per ton to demand in heating units.

Potential blends that could be shipped from a blending plant to a user were selected on the basis of the Btu and SO_2 of raw Iowa strip mine coal. Only the Iowa strip mine coal was assumed to be blended with Wyoming coal. The two deep mines were excluded because the quality of the coal meets many Iowa user SO_2 standards. Table 3.21 presents the Btu and SO_2 of the eight Iowa coal types. The Gillette, Wyoming source chosen has 16.2 million Btu's per ton and 19.44 pounds of SO_2 per ton. The eight blends of Iowa and Wyoming coal were estimated by the following equation:

Table 3.21. Million Btu per ton and pounds of sulfur dioxide per ton by Iowa mine location

Iowa type	Mine Location[a]	Million Btu per ton	Pounds SO_2 per ton
1	Group VI	21.596	124.4
2	Group V	20.362	129.6
3	Group VIII	23.098	170.8
4	Group I	19.588	210.0
5	Group II	19.702	213.2
6	Group VII	20.588	219.6
7	Group IV	21.800	224.0
8	Group III	20.696	233.2

[a]See Table 3.2 and Map 3.4.

$$K = \{(I\ SO_2)(X) + (W\ SO_2)(Y)\}\{(I\ Btu)(X) + (W\ Btu)(Y)\}^{-1} \tag{3.5}$$

where

K = sulfur standard,

$I\ SO_2$ = pounds of SO_2 per ton of Iowa coal,

$W\ SO_2$ = pounds of SO_2 per ton of Wyoming coal,

I Btu = million Btu per ton of Iowa coal,

W Btu = million Btu per ton of Wyoming coal,

X = percent of Iowa coal, and

Y = 1-X = percent of Wyoming coal.

The emission standards that are applicable to Iowa users are five, six, and eight pounds of sulfur dioxide per million Btu. The users at Sergeant Bluff, Council Bluffs, and Lansing were assigned a weighted average of the sulfur standards applicable to different boilers at each user. After substituting Y = 1-X, the equation is solved for X for each of the six standards. Table 3.22 presents the percents of Iowa coal to be blended with Wyoming coal that meets the sulfur standards. A ninth blend consisting of 100 percent Wyoming coal was selected to allow a blending plant to act as a transshipment plant. Applying these percentages to the Btu and SO_2 content of Iowa and Wyoming coal, the nine blends of coal for each sulfur standard can be estimated. These estimated blends specifying Btu and SO_2 are minimum blends that will satisfy a user's demand. Although this may not be the most efficient, the model does not preclude the possibility of blending several types of the estimated blends or the possibility of blending Iowa coal with another coal other than Wyoming coal. Tables 3.23 and 3.24 present the Btu and SO_2 of the nine estimated blends by sulfur standards.

Table 3.22. Percent of Iowa coal to be blended with Wyoming coal for the different Iowa sulfur standards by coal types

Blend types	Sulfur standards					
	5	6	8	Sergeant Bluff	Council Bluffs	Lansing
1	78.9	87.5	87.5	87.5	18.3	8.2
2	68.9	87.5	87.5	79.1	16.8	7.6
3	52.7	70.7	87.5	60.9	12.5	5.6
4	35.5	45.7	67.4	40.2	9.3	4.3
5	34.9	45.0	66.5	39.6	9.1	4.2
6	34.5	44.7	66.7	39.3	8.9	4.1
7	34.9	45.5	69.0	39.8	8.8	4.0
8	32.2	41.6	62.0	36.6	8.3	3.8
9	0.0	0.0	0.0	0.0	0.0	0.0

Table 3.23. Estimated Btu of blended Iowa and Wyoming coal by Iowa sulfur standards in million Btu per ton by type of blend

Blend types	Sulfur standards					
	5	6	8	Sergeant Bluff	Council Bluffs	Lansing
1	20.460	20.922	20.922	20.922	17.185	16.642
2	19.068	19.842	19.842	19.493	16.900	16.517
3	19.833	21.078	22.236	20.398	17.060	16.588
4	17.401	17.748	18.483	17.562	16.514	16.344
5	17.423	17.776	18.527	17.587	16.519	16.346
6	17.716	18.163	19.129	17.923	16.591	16.379
7	18.153	18.747	20.061	18.427	16.694	16.426
8	17.646	18.072	18.986	17.844	16.574	16.371
9	16.200	16.200	16.200	16.200	16.200	16.200

Table 3.24. Estimated SO_2 of blended Iowa and Wyoming coal by Iowa sulfur standards in pounds of SO_2 per ton by type of blend

Blend types	Sulfur standard 5	6	8	Sergeant Bluff	Council Bluffs	Lansing
1	102.295	111.280	111.280	111.280	38.595	28.041
2	95.340	115.830	115.830	106.607	37.957	27.831
3	99.161	126.467	151.880	111.556	38.315	27.946
4	87.005	106.488	147.858	96.045	37.086	27.539
5	87.115	106.651	148.213	96.183	37.101	27.539
6	88.575	108.972	153.027	98.020	37.254	27.598
7	90.765	112.474	160.484	100.773	37.494	27.677
8	88.228	108.428	151.886	97.588	37.225	27.584
9	19.440	19.440	19.440	19.440	19.440	19.440

CHAPTER IV. RESULTS

The main purpose of this study was to evaluate the economics of blending Iowa coal. A linear programming model was used to minimize the cost of supplying Iowa users' projected 1980 coal consumption subject to the constraints described in Chapter II. The cost of supplying Iowa users' projected 1980 coal consumption includes the FOB price of coal at the origins, transportation and handling costs, coal beneficiation costs, coal blending costs, and additional investment costs for upgrading users' receiving capacity. The optimal solution identifies the "best" system of transporting coal which will meet Iowa's projected 1980 coal consumption.

Assumptions

The assumptions made in this analysis are summarized as follows:

1. Each township in the 3½ county area in Iowa having available strippable reserves can support up to two mines producing a total of 120,000 tons for ten years. Townships with less than 1.2 million tons could support two mines, each producing five

percent of the reserves annually.[1]

2. All Iowa strip mine coal must be processed through a coal beneficiation plant or blended through a blending plant.

3. Iowa and Missouri FOB mine prices are based on the average price per ton of $17.33 -- the estimated average cost of mining Iowa coal in a typical mining operation.

4. Coal will be trucked from underground mines and beneficiation plants to users in a tandem-axle dump truck with a pup trailer. Coal will be trucked from strip mines to blending plants and from blending plants to users in a tandem-axle dump truck with a pup trailer. All return trips are empty.

5. Blending plants can receive non-Iowa coal in 100-car unit trains. Iowa coal can be delivered to blending plants by truck, single-car, 15-car, and 50-car units.

6. The cost of coal delivered to users includes the FOB mine price, beneficiation costs, blending costs, and all transportation and handling costs. The additional investment cost for receiving multiple-

---

[1]Lemish, John and Lyle V. A. Sendlein. Information on potential number of coal strip mines in townships of a 3½ county area in southeast Iowa. Personal communication. Department of Earth Science, Iowa State University, Ames, Iowa, January 1977.

car rail shipments is included for those which upgrade to the next larger size.

7. Each users' consumption expressed in heating units must be satisfied with coal that will not exceed its sulfur dioxide emission standard.

Results

This study provides a comparison of results from two computer solutions. Solution I was taken from an unpublished report from Baumel, Drinka, and Miller (2). Solution I is based on Ex Parte 336 rail rates and estimated multiple rail rates, an average Iowa FOB mine price of $17.33 per ton, and 1977 non-Iowa FOB mine prices plus reclamation costs. Solution II -- obtained in this analysis -- is based on the same data as Solution I, but includes the alternative of blending Iowa and Wyoming coals. Therefore, Solutions I and II provide an evaluation of the impact of blending coal on Iowa coal production and on the total cost of satisfying the projected 1980 Iowa coal requirements.

The model determines the optimal amount of coal for each user from each origin, the optimal mode of transporting the coal, the optimal number and location of coal beneficiation plants in Iowa, the optimal number and location of coal blending plants in Iowa, and which Iowa users should upgrade their receiving capacity to the next larger shipment size.

Solution I

Solution I is based on Ex Parte 336 rail rates and estimated multiple-car rates, existing rail-barge rates, estimated trucking rates, and an average Iowa FOB mine price of $17.33 per ton. The average Iowa FOB mine prices represent the estimated total cost of opening and operating a new Iowa mine producing 70,000 tons per year under typical mining operations and includes reclamation costs and 15 percent profit on sales.

The origins of coal consumption for Iowa users under Solution I is presented in Table 4.1. Iowa mines would supply only about six percent of the projected 1980 coal consumed

Table 4.1. Estimated quantities of coal consumed in Iowa in 1980 by origin of coal under Solution I (2)

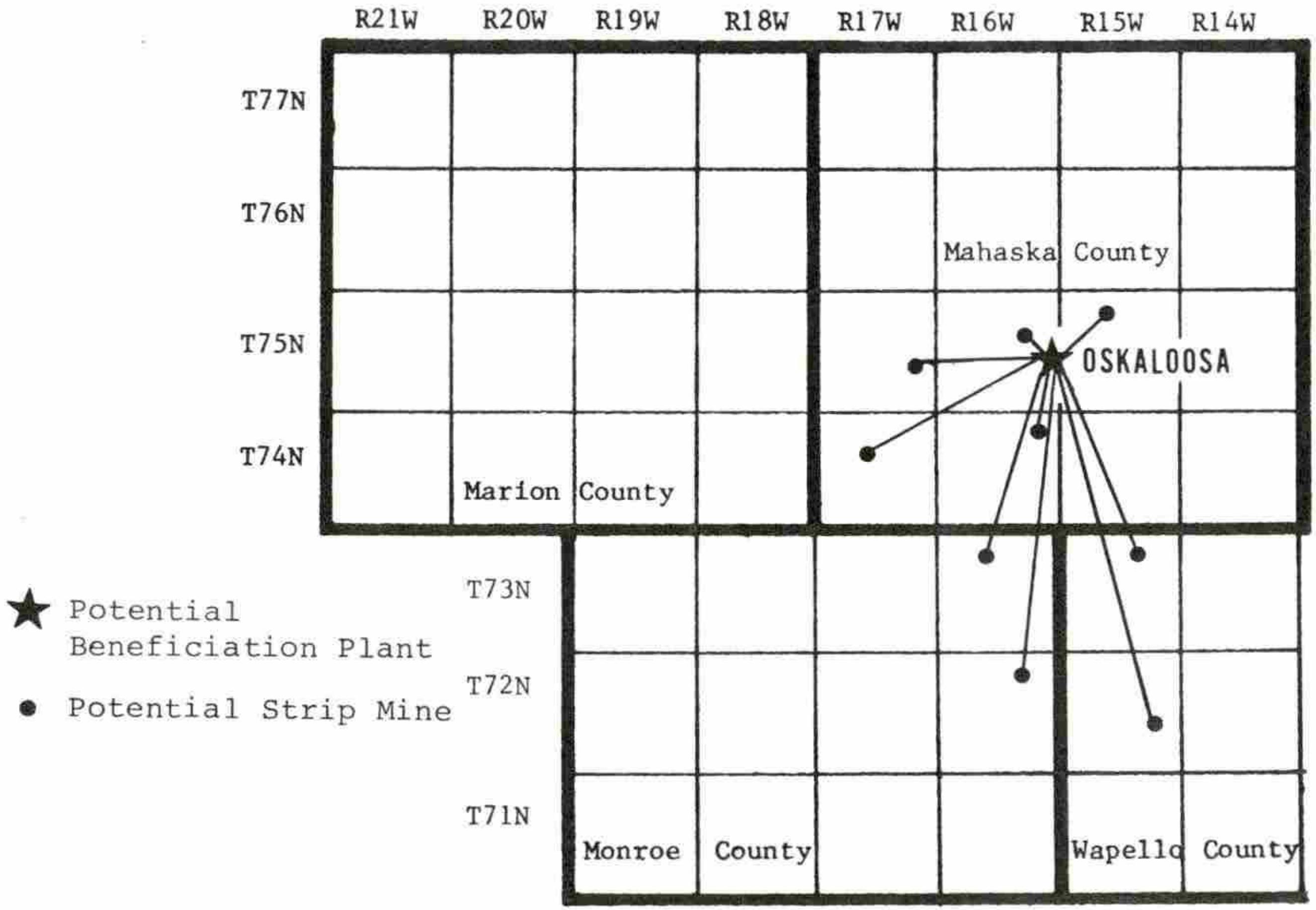
Coal origins	Tons	Percent of total
Wyoming	11,096,220	67.4
Illinois	4,419,560	26.8
Kentucky	0	0
Missouri	0	0
Iowa		
Underground mine	307,290	1.9
Beneficiated strip mine	646,800[a]	3.9
TOTAL	16,469,870	100.0

[a]Would require 840,000 tons of raw coal to yield 646,800 tons of clean coal.

in Iowa, down from seven percent in 1976. The six percent includes 307,290 tons of underground mine coal and 646,800 tons of beneficiated strip mine coal. The beneficiated coal would be processed at one beneficiation plant located at Oskaloosa. This plant would produce at capacity requiring 840,000 tons of raw strip mine coal. Wyoming would supply about 67 percent of the coal consumed in Iowa and Illinois would supply 27 percent of the coal consumed in Iowa. No coal would be consumed from either Kentucky or Missouri. In 1976, Wyoming supplied 40 percent and Illinois supplied 36 percent to Iowa. Western Kentucky supplied about three percent and Missouri supplied six percent of the coal consumed in Iowa in 1976. Thus, under Solution I, a larger proportion of Iowa coal consumption would come from Wyoming and Iowa coal and a smaller proportion would come from Illinois, Kentucky and Missouri.

Map 4.1 presents the flow of coal from Iowa strip mines to the beneficiation plant located at Oskaloosa. The beneficiation plant would receive coal by truck from mines located up to 25 miles from the coal beneficiation plant.

The percent of total consumption and mode of transportation from the coal origins to the users is presented in Table 4.2. Wyoming coal would be received by seven users in large shipment sizes -- 50-car or 100-car units. Six users would receive all of their coal from Wyoming by rail. The



Map 4.1. Estimated 1980 flow of coal from Iowa mines to coal beneficiation plants under Solution I (2)

Table 4.2. Mode of transport and percent of 1980 coal consumption by Iowa users and coal origin under Solution I (2)

Iowa destination	Wyoming		Illinois		Iowa underground mines		Beneficiation plant at Oskaloosa	
	Percentage	Mode	Percentage	Mode	Percentage	Mode	Percentage	Mode
Spencer (CBPC)			100	15-car				
Spencer (SMU)			100	single-car				
Sergeant Bluff	100	100-car trains						
Council Bluffs	100	100-car trains						
Mason City (LPCC)			43.8	15-car			56.2	15-car
Mason City (NSPCC)			100	15-car				
Humboldt			100	15-car				
Iowa Falls					100	truck		
Cedar Falls (CFU)			100	15-car				
Cedar Falls (UNI)			15.0	single-car			85.0	truck
Waterloo (IPSC)			100	15-car				
Waterloo (RPC)			100	15-car				
Waterloo (UDWTW)			100	15-car				
Boone					100	truck		
Ames (AMES)					18.9	truck	81.1	15-car
Ames (ISU)							100	15-car
Marshalltown	100	50-car trains						
West Des Moines (PDCC)					11.5	truck	88.5	single-car
West Des Moines (MCMC)					56.5	truck	43.5	single-car
Des Moines	100	100-car trains						
Pella					100	truck		
Chillicothe	100	100-car trains						
Bridgeport Station					100	truck		
Lansing	82.4	100-car trn,brg	17.6	barge				
Dubuque (CC)			100	single-car				
Dubuque (IPC)			100	barge				
Dubuque (UUDIW)			100	15-car				
Cedar Rapids (IELPC,PC)	100	50-car trains						
Cedar Rapids (IELPC,6th)			100	15-car				
Cedar Rapids (WFC)			43.8	single-car			56.2	truck
Clinton (CCPC)			100	15-car				
Clinton (EIDNC)			100	15-car				
Clinton (IPC)			100	barge				
Iowa City			100	15-car				
Davenport (LSPC)			100	barge				
Davenport (OMC)			100	15-car				
Davenport (RPC)			100	single-car				
Bettendorf (IIGEC)			100	50-car				
Bettendorf (JIC)			100	single-car				
Montpelier			100	barge				
Muscatine (MPW)			100	barge				
Muscatine (GC)			100	15-car				
Buffalo							100	truck
Middletown			100	15-car				
Burlington			100	50-car				
Keokuk			100	barge				

other user would receive 82 percent of its coal from Wyoming by 100-car rail-barge. All Iowa underground mine coal would be shipped by truck to users located in central Iowa or near the Iowa mine area. Users at Ames and one user in Mason City would receive 15-car rail shipments of beneficiated coal from the beneficiation plant at Oskaloosa. West Des Moines would receive beneficiated coal in single-car rail shipments. The rest of the beneficiated coal would be transported to Iowa users by truck.

Table 4.3 presents a list of those users which would expand their receiving facilities to receive the next larger size of rail shipment. Eight single-car receivers would upgrade to receive the 15-car size, four 15-car receivers would upgrade to receive the 50-car size, and only one 50-car receiver would upgrade to receive 100-car shipments.

Table 4.4 presents the proportion of coal received by mode. Nearly 55 percent of the Iowa coal -- including underground and beneficiated coal -- would be transported to users by truck. In 1976, 89 percent of the Iowa coal was transported by truck. The remaining 45 percent of Iowa coal would be shipped by rail with about 32 percent of the total Iowa coal transported to Iowa users by 15-car shipments. Fifty-eight percent of the out-of-state coal would be transported in 100-car unit trains. The remaining 42 percent of the

Table 4.3. List of Iowa users expanding to the next larger size by location under Solution I (2)

Upgrading	Location	User
Single-car to 15-car	Humboldt	Corn Belt Power Coop.
	Waterloo	The Rath Packing Co.
	Waterloo	John Deere Waterloo Tractor Works
	Dubuque	John Deere Dubuque Tractor Works
	Clinton	E. I. DuPont de Nemours & Co.
	Iowa City	University of Iowa
	Davenport	Oscar Mayer & Co.
	Muscatine	Grain Processing Corp.
15-car to 50-car	Marshalltown	Iowa Elec. Light & Power Co.
	Cedar Rapids	Iowa Elec. Light & Power Co. (Prairie Creek Sta.)
	Bettendorf	Iowa-Ill. Gas & Elec. Co.
	Burlington	Iowa Southern Util. Co.
50-car to 100-car	Des Moines	Iowa Power & Light Co.

Table 4.4. Estimated 1980 tons of coal transported to Iowa users by mode and coal origin under Solution I (2)

Mode of transport	Iowa coal		Out-of-state coal	
	Tons	Percent	Tons	Percent
Truck	519,730	54.47	0	
Rail				
Single-car	133,280	13.97	57,950	0.37
15-car	301,080	31.56	1,920,500	12.38
50-car	0		2,543,920	16.40
100-car	0		8,922,120	57.50
Rail-barge	0		2,071,290	13.35
TOTAL	954,090	100.00	15,515,780	100.00

out-of-state coal would be transported in 15-car, 50-car, and rail-barge shipments.

The distribution of coal among users with different SO_2 emission standards is presented in Table 4.5. Approximately 47 percent of the beneficiated Iowa coal would be consumed by users with an eight-pound SO_2 emission standard. About 30 percent of the beneficiated Iowa coal would be consumed by six-pound standard users and just over 23 percent would be consumed by users with a five-pound standard. No beneficiated Iowa coal would be consumed by users with a 1.2-pound standard. However, the users with a 1.2-pound SO_2 standard would consume nearly 60 percent of the non-Iowa coal.

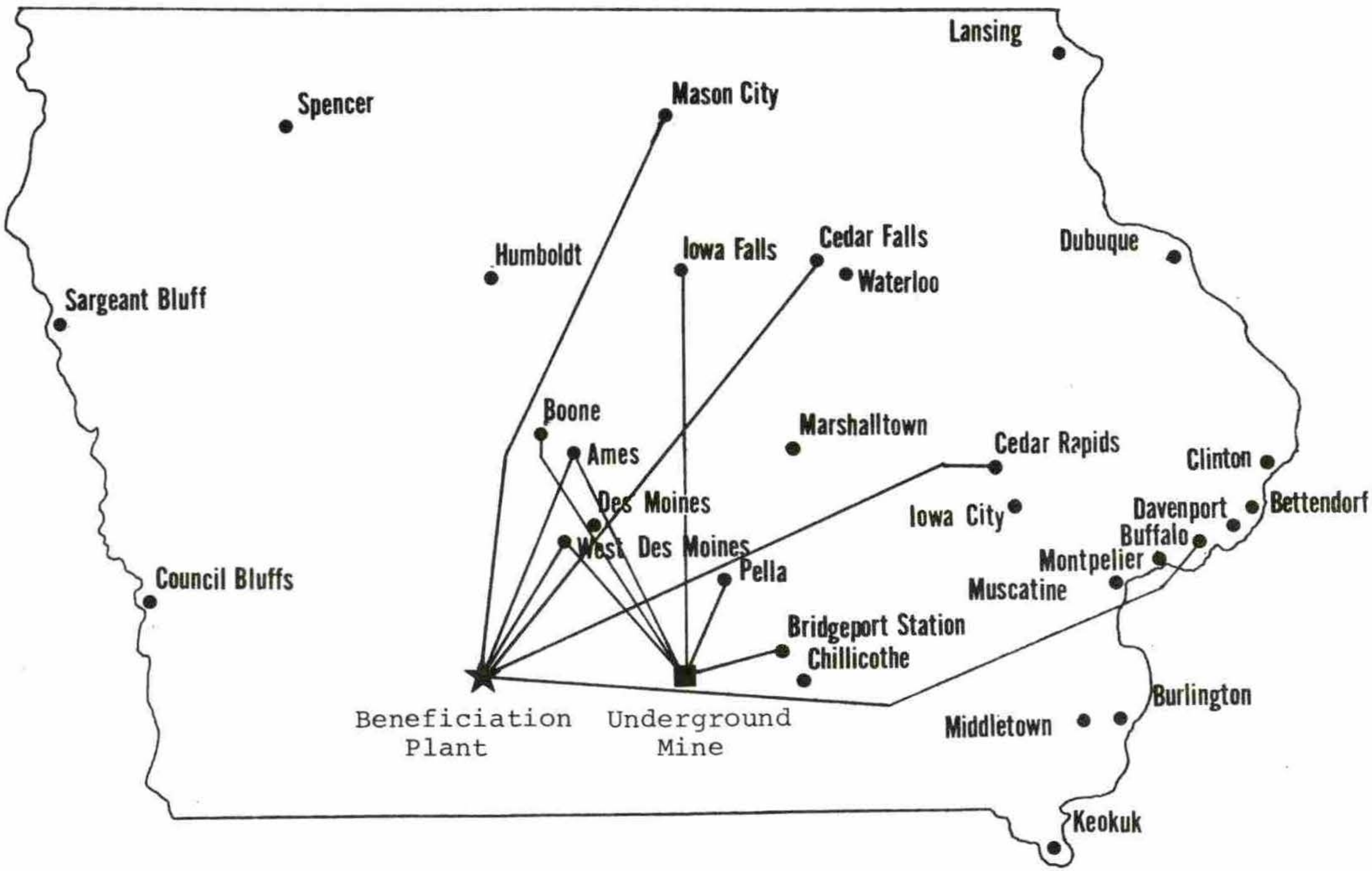
Map 4.2 shows the distribution of Iowa coal to Iowa users. A large percent of the Iowa coal would be transported to the central and east-central portion of Iowa. A small amount, however, would be shipped to two users located near the Mississippi River and to one user in north-central Iowa.

Solution II

Solution II differs from Solution I in that it includes a coal blending alternative thus providing an evaluation of the impact of blending on Iowa coal production and transportation. Solution II determines the optimal number and location of coal blending plants in Iowa as well as the

Table 4.5. Estimated 1980 coal consumption by Iowa users by SO_2 emission level and coal origin under Solution I (2)

Assumed maximum SO_2 emission level in pounds per million Btu	Iowa coal				Out-of-state coal	
	Beneficiated		Underground			
	Tons	Percent	Tons	Percent	Tons	Percent
1.2	0	0.00	0	0.00	9,219,050	59.42
5	151,310	23.39	49,150	15.99	1,573,820	10.14
6	194,410	30.06	0	0.00	3,590,940	23.14
8	301,080	46.55	258,140	84.01	1,131,970	7.30
TOTAL	646,800	100.00	307,290	100.00	15,515,780	100.00



Map 4.2. Estimated 1980 flow of coal from underground mines and beneficiation plants under Solution I (2)

optimal amount of coal for each user from each origin, the optimal mode of transporting the coal, the optimal number and location of coal beneficiation plant, and which Iowa users should upgrade their receiving capacity to the next larger size rail shipment.

The total cost of supplying Iowa's 1980 projected coal consumption under Solution II was estimated to be $320,734,289 while the total cost under Solution I was estimated to be $328,014,500. Thus, the estimated total cost of supplying Iowa's 1980 projected coal consumption would decrease by $7.3 million if Iowa and Wyoming coal were blended at central blending points and then transshipped to Iowa coal users.

Table 4.6 presents the origins of coal consumption for Iowa users under Solution II. Wyoming would supply roughly 78 percent of the 1980 estimated coal consumption compared to 67 percent under Solution I -- an increase of 2.6 million tons in Solution II over Solution I. Illinois would supply about 12.5 percent of the estimated 1980 coal consumption compared to 27 percent under Solution I -- a decrease of 2.2 million tons. Kentucky and Missouri would not supply any coal to Iowa users under either solutions. Iowa underground coal would remain at 307,290 tons under both solutions. Raw Iowa strip mine coal production would be 1,299,000 tons under Solution II. However, no Iowa coal would be beneficiated under Solution II while 840,000 tons of raw Iowa strip mine

Table 4.6. Estimated quantities of 1980 coal consumed in Iowa by origin under Solution II

Origin	Tons of coal	Percent of total
Wyoming	13,727,978	78.4
Illinois	2,182,461	12.45
Kentucky	0	0.0
Missouri	0	0.0
Iowa		
Underground mine	307,290	1.75
Raw strip mine	1,299,000	7.4
Beneficiated strip mine	0	0.0
TOTAL	17,516,729	100.00

coal would be mined and beneficiated under Solution I.

Under Solution II, blending plants would be constructed at Marshalltown, Chillicothe, Cedar Rapids, and Muscatine. Table 4.7 presents the tons of coal received by the blending plants. Over 5.5 million tons of coal or about 32 percent of Iowa's projected 1980 coal consumption would move through blending plants. All coal from Wyoming would be shipped to blending plants in 100-car unit trains. Map 4.3 presents the flow of raw Iowa strip mine coal to the Iowa blending plants. Raw Iowa strip mine coal would be shipped to blending plants by truck. Chillicothe would receive Iowa strip mine

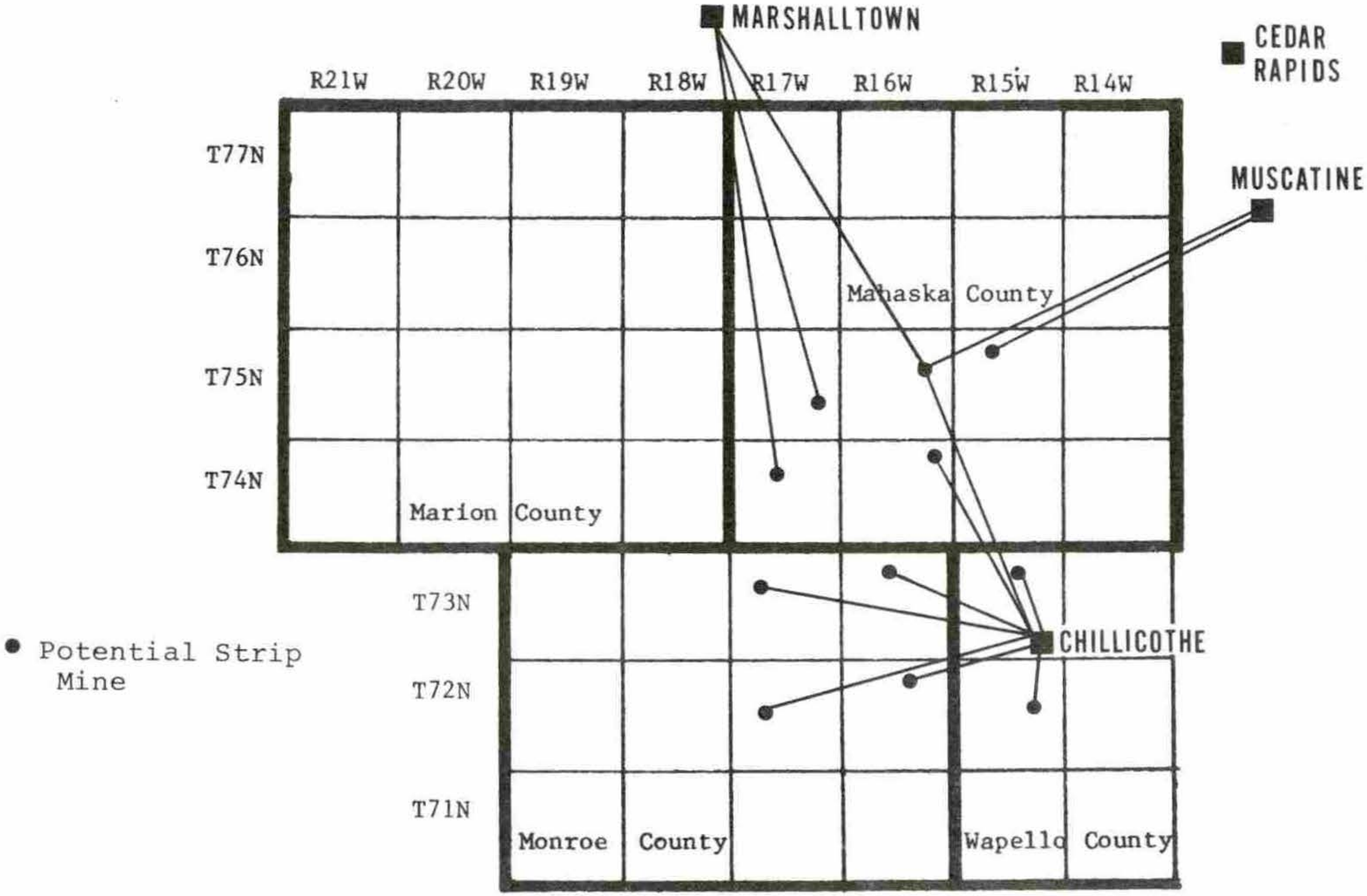
Table 4.7. Estimated 1980 tons of coal received by blending plants by origin under Solution II

Blending plants	Origin: Iowa strip mine	Origin: Wyoming	Total
Marshalltown	300,862	1,408,429	1,709,291
Chillicothe	869,403	212,095	1,081,498
Cedar Rapids	0	1,507,185	1,507,185
Muscatine	128,735	1,123,112	1,251,847
TOTAL	1,299,000	4,250,821	5,549,821

coal from no father than 25 miles. Iowa strip mine coal would be hauled about 65 miles to Marshalltown and about 95 miles to Muscatine.

Table 4.8 presents the percent of total consumption and mode of transportation from the coal origins to the Iowa users. Four users would receive 100 percent of their coal from Wyoming in 100-car unit trains. One user would receive 82.4 percent of its coal from Wyoming.

Thirty users would receive coal from a blending plant. Three users would receive coal from a blending plant in 50-car units, two users would receive blended coal in 15-car units, one user would receive blended coal in single-car units, and 21 users would receive blended coal by truck.



Map 4.3. Estimated 1980 flow of raw Iowa strip mine coal to coal blending plants under Solution II

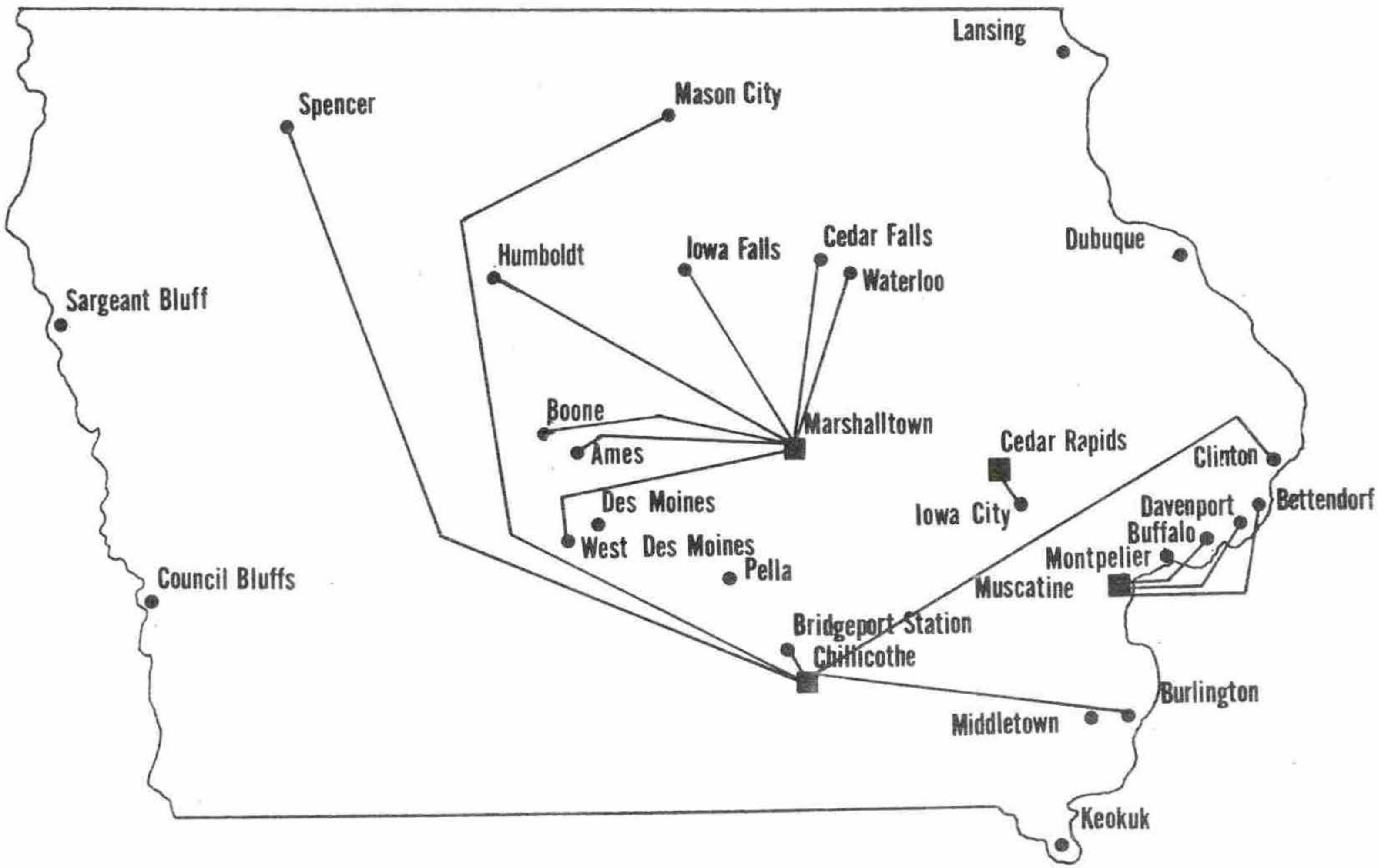
Table 4.8. Mode of transport and percent of 1980 coal consumption received by Iowa users by coal origin under Solution II

Destination	Wyoming		Illinois		Iowa underground mines		Blending plant	
	Percent	Mode	Percent	Mode	Percent	Mode	Percent	Mode
Spencer (CBPC)							100	15-car
Spencer (SMU)							100	single-car
Sergeant Bluff	100	100-car						
Council Bluffs	100	100-car						
Mason City (LPCC)							100	15-car
Mason City (NSPCC)							100	50-car
Humboldt					36.3	truck	63.7	truck
Iowa Falls							100	truck
Cedar Falls (CFU)							100	truck
Cedar Falls (UNI)							100	truck
Waterloo (IPSC)							100	truck
Waterloo (RPC)							100	truck
Waterloo (JDWTW)							100	truck
Boone							100	truck
Ames (AMES)							100	truck
Ames (ISU)							100	truck
Marshalltown							100	–[a]
West Des Moines (PDCC)					81.5	truck	18.5	truck
West Des Moines (MCMC)					81.5	truck	18.5	truck
Des Moines	100	100-car						
Pella					100	truck		
Chillicothe	100	100-car						
Bridgeport Station							100	truck
Lansing	82.4	100-car rail, barge	17.6	barge				
Dubuque (CC)			100	single-car				
Dubuque (IPC)			100	barge				
Dubuque (JDDTW)			100	15-car				
Cedar Rapids (IELPC,PC)							100	truck
Cedar Rapids (IELPC,6th)							100	–[a]
Cedar Rapids (WFC)							100	truck
Clinton (CCPC)			18.9	50-car			81.1	50-car
Clinton (EIDNC)			100	15-car				
Clinton (IPC)			100	barge				
Iowa City							100	truck
Davenport (LSPC)			100	barge				
Davenport (OMC)							100	truck
Davenport (RPC)							100	truck
Bettendorf (IIGEC)			100	barge				
Bettendorf (JIC)							100	truck
Montpelier			100	barge				
Muscatine (MPW)							100	–[a]
Muscatine (GPC)							100	truck
Buffalo							100	truck
Middletown			100	barge				
Burlington			36.2	50-car			63.8	50-car
Keokuk			100	barge				

[a]Users selected as blending sites would receive their coal through the blending plants.

Users at Marshalltown, Cedar Rapids, and Muscatine selected under Solution II as blending plant sites would receive their coal through the blending plant. The flow of coal from the blending plants to the users is shown in Map 4.4. Chillicothe is the only blender that ships by rail -- which accounts for 30 percent of the coal shipped to Iowa users -- because this plant would supply the more distant users at Spencer, Mason City, Clinton, and Burlington. Chillicothe would supply the more distant users because Chillicothe is located near the Iowa producing mines and would receive a direct route from Wyoming. Therefore, Chillicothe would receive both raw Iowa strip mine coal and Wyoming coal at low transportation costs. The reduced assembly costs for Chillicothe compared to other selected blending plants would more than offset the increase in the transportation cost to supply the more distant users.

A list of the coal users that would upgrade their rail receiving capacity is presented in Table 4.9. Under Solution II, only two users would upgrade their rail receiving facilities from single-car to 15-car shipments compared to eight users that would upgrade under Solution I. Three users would upgrade from 15-car to 50-car shipments under Solution II. Under Solution I, four users would upgrade from 15-car to 50-car shipments. The user at Des Moines would upgrade from a 50-car to a 100-car receiver under both solutions.



Map 4.4. Estimated 1980 flow of coal from coal blending plants to users under Solution II

Table 4.9. List of Iowa users expanding to the next larger shipment size by location under Solution II

Upgrading	Location	User
Single-car to 15-car	Dubuque	John Deere Dubuque Tractor Works
	Clinton	E. I. DuPont de Nemours & Co.
15-car to 50-car	Mason City	Northwestern States Portland Cement Co.
	Clinton	Clinton Corn Processing Co.
	Burlington	Iowa Southern Utilities Co.
50-car to 100-car	Des Moines	Iowa Power & Light Company

Fewer users would upgrade their rail receiving facilities under Solution II than under Solution I because it would be cheaper to receive coal by truck from the blending plants than by rail directly from mines or coal beneficiation plants.

Table 4.10 presents the tons of each blend of coal which would be transported to Iowa coal users. Approximately 3.5 million tons of coal received by Iowa users from blending plants is 100 percent Wyoming coal. Of the 3.5 million tons of Wyoming coal, 2.1 million tons would be used by the utility plants which were selected as blending sites. The remaining 1.4 million tons of Wyoming coal would be received by the blending plants in 100-car unit trains, unloaded, and distributed to Iowa users without blending it with raw

Table 4.10. Estimated 1980 tons of blended coal received by users by type of blend under Solution II

Blend percentage		Tons	Percent of total
Iowa	Wyoming		
70.7	29.3	369,384	6.7
87.5	12.5	161,223	2.9
45.7	54.3	612,829	11.0
67.4	32.6	156,264	2.8
45.0	55.0	76,058	1.4
69.0	31.0	652,356	11.7
0.0	100.0	3,521,707	63.5
TOTAL		5,549,821	100.0

Iowa strip mine coal. The 2.0 million tons of blended coal shipped from blending plants would contain from 45 to 88 percent raw Iowa strip mine coal.

Table 4.11 presents a comparison of estimated FOB blend plant prices of selected types of blended coal at the Marshalltown blending plant. The utility at Marshalltown would receive 100 percent Wyoming coal from the blending plant. The estimated price paid for 100 percent Wyoming coal would be \$0.9920 per million Btu compared to \$1.0115 per million Btu for a blended coal consisting of 62 percent raw Iowa strip mine coal and 38 percent Wyoming coal. A blend of raw Iowa

Table 4.11. Estimated FOB blend plant prices at the Marshalltown blending plant for users with an eight-pound SO_2 emission standard by type of blend in dollars per ton and dollars per million Btu

Location of Iowa mines	Type of coal blended	Estimated FOB price at Marshalltown[a]	
		per ton	per MBtu
	0% Iowa, 100% Wyoming	\$16.07[b]	\$0.9920[b]
	0% Iowa, 100% Wyoming	16.895	1.0429
T75N,R17W	62% Iowa, 38% Wyoming	19.208	1.0115
T77N,R19W	67.4 Iowa, 32.6% Wyoming	19.288	1.0435

[a]Estimated FOB price includes the estimated FOB price at the mine plus all estimated transportation and handling costs.

[b]Estimated FOB price for the Marshalltown utility excludes the variable blending cost.

strip mine coal and Wyoming coal would be less expensive than 100 percent Wyoming coal. The FOB price at the Marshalltown blending plant would be \$1.0115 per million Btu for 62 percent raw Iowa strip mine coal from mine T75N, R17W (see Maps 3.2 and 3.4). The estimated FOB price at the blender for 100 percent Wyoming coal would be \$1.0429 per million Btu. Therefore, it would be cheaper for a user located in central Iowa -- not at Marshalltown -- to purchase blended coal rather than 100 percent Wyoming coal. The blending plants would transship 1.4 million tons of 100 percent Wyoming coal because after the Iowa coal having the qualities of mine T75N, R17W would be exhausted, the next "best" Iowa strip mine coal would have the same qualities as Iowa mine T77N, R19W. The estimated FOB price for blended coal consisting of

67.4 percent raw Iowa strip mine T77N, R19W coal would be \$1.0435 per million Btu which is slightly more expensive than the FOB price for 100 percent Wyoming coal of \$1.0429 per million Btu.

If the Wyoming FOB mine price would be increased by two or more cents per ton, the blend of 67.4 percent Iowa coal would be less costly than 100 percent Wyoming coal. Thus a small change in the FOB mine prices would cause more Iowa strip mine coal to be blended. A range analysis would provide a range of values that would not alter the optimal solution for each row and column activity and for each objective function coefficient. However, a range analysis was not run because of its expense and limited funds.

Table 4.12 presents the estimated 1980 tons of coal transported from the origins to users by mode. Over three-fourths of the nonblended out-of-state coal would be shipped from the mines to the users in 100-car unit trains under Solution II compared to only 58 percent shipped directly to users in 100-car unit trains under Solution I. The number of tons of coal shipped from out-of-state mines to users in 15-car shipments would decline from 12 percent under Solution I to two percent in Solution II while 50-car shipments would decline from 16 percent under Solution I to six percent under Solution II. The major reason for these changes is the large number of tons that would be moved through the blending

Table 4.12. Estimated 1980 tons of coal transported to Iowa users by mode and coal origin under Solution II

Mode of transport	Underground Iowa coal		Nonblended out-of-state coal		Blended coal	
	Tons	Percent	Tons	Percent	Tons	Percent
Truck	307,290	100.00	0		2,438,099	70.12
Rail						
Single-car			11,851	0.10	1,124	0.03
15-car			245,644	2.11	280,863	8.08
50-car			731,080	6.27	756,970	21.77
100-car			8,922,120	76.52	0	
Rail-barge			1,748,923	15.00	0	
TOTAL	307,290	100.00	11,659,618	100.00	3,477,056	100.00

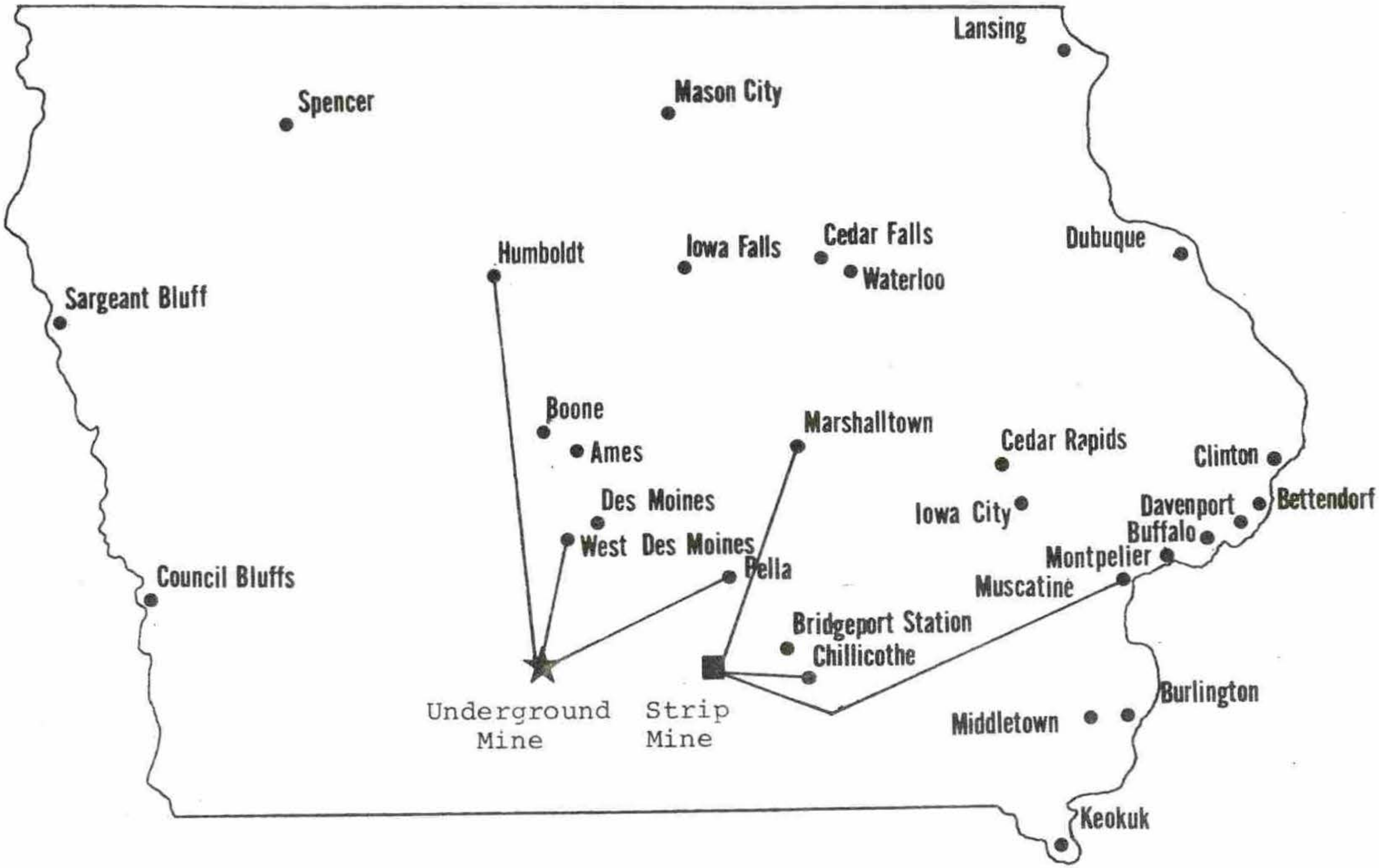
plants. The basic mode of transportation for blended coal would be truck, which accounts for 70 percent of the coal shipped from blending plants. Eight percent of the blended coal would be transported in 15-car units and 22 percent would be transported in 50-car units. Approximately 2.1 million tons accounting for 37 percent of the coal received by all blending plants would be used by those utility plants that were selected as blending sites under Solution II.

Table 4.13 presents the distribution of coal by SO_2 emission standards. The Iowa underground mine coal would be shipped to five-pound and eight-pound standard coal users. The non-Iowa coal excludes coal transported to a blending plant. Users with the 1.2-pound SO_2 standard would receive 79 percent of the non-Iowa coal. The blended coal would be distributed fairly even among the five-, six-, and eight-pound standard users. The five-pound standard users would receive 25 percent, six-pound users would receive 42 percent, and eight-pound users would receive 33 percent of the blended coal consisting of Wyoming coal and raw Iowa strip mine coal.

Map 4.5 shows the distribution of Iowa coal to Iowa users and to Iowa blenders. Under Solution II, Iowa underground mine coal would be transported by truck to Humboldt, West Des Moines, and Pella. All Iowa strip mine coal would be transported to blending plants by trucks.

Table 4.13. Estimated 1980 coal consumption by Iowa users by SO_2 emission level and coal origin under Solution II

Assumed maximum SO_2 emission level in pounds per million Btu	Underground Iowa coal		Nonblended out-of-state coal		Blended coal	
	Tons	Percent	Tons	Percent	Tons	Percent
1.2	0		9,219,040	79.07	0	0
5	186,417	60.66	376,543	3.23	1,386,617	24.98
6	0		2,064,035	17.70	2,339,693	42.16
8	120,873	39.34	0		1,823,511	32.86
TOTAL	307,290	100.00	11,659,618	100.00	5,549,821	100.00



Map 4.5. Estimated 1980 flow of Iowa underground mine coal and Iowa strip mine coal to Iowa users and Iowa blending plants under Solution II

CHAPTER V. SUMMARY AND CONCLUSIONS

The United States switched from coal to oil and natural gas as the main energy source in the mid 1900's. However, coal is the most abundant of the nation's proven energy reserves. Declining domestic oil and natural gas reserves and increasing cost of imported energy has focused attention on coal and nuclear power for energy sources. With reservations about nuclear power, the nation seems to be looking at coal for the primary energy source at least in the short run.

Iowa is a net importer of coal. In 1976, Iowa coal users consumed about 7.9 million tons of coal. But, Iowa mines produced only 540,000 tons of coal in 1976. In fact, Iowa's coal industry has been declining while the Iowa demand for coal has been increasing. Several reasons that may explain this decline are:

1. high sulfur content of Iowa coal,
2. pyrite and rock in Iowa coal causing high maintenance costs for equipment,
3. deep underground location and thinness of Iowa coal seams, and
4. small scale of Iowa mining operations and relatively high costs.

Iowa coal users project they will consume 16 million tons of coal in 1980 and 18.5 million tons of coal in 1985. Thus, to what extent will the Iowa coal industry participate in the increasing demand for coal?

The main purpose of this study was to evaluate the economic impact of blending coal on Iowa coal production and transportation. A mathematical mixed integer programming model was used to minimize the cost of supplying Iowa's projected 1980 coal consumption. The model was constrained by Iowa mining capacity, user receiving capacity, and user sulfur dioxide emission standards. The model includes data on coal origins, Iowa coal users, coal transportation rates by mode and size of shipment, coal beneficiation location and costs, and coal blending locations and costs.

Two solutions were analyzed in this study. Solution I minimizes the cost of supplying Iowa's 1980 Btu coal requirements subject to mining capacity, beneficiation plant capacity, receiving capacity of users, sulfur dioxide emissions, and transportation rates. Solution II extends Solution I by adding the alternative of blending raw Iowa strip mine coal with low sulfur Wyoming coal at central coal blending plants.

The major findings from the blending analysis are:

1. Blending raw Iowa strip mine coal with Wyoming coal would increase the level of Iowa coal production. The estimated raw Iowa strip mine coal produced in 1980 would increase from 840,000 tons in Solution I -- which precludes the possibility of blending --

to 1,299,000 tons under Solution II which includes the blending alternative.

2. Blending Wyoming coal with Iowa strip mine coal would result in a substitution of Wyoming and Iowa coal for Illinois and Missouri coal.
3. The blending solution would reduce the estimated cost of supplying the 1980 Iowa projected coal consumption by $7.3 million compared to Solution I. The reason for the large reduction in the total cost of supplying the 1980 Iowa coal requirements under the blending alternative is the large increase in the amount of Wyoming coal that would be purchased at lower FOB prices and shipped in low cost 100-car unit trains.
4. Four blending plants would be located at Cedar Rapids, Chillicothe, Marshalltown, and Muscatine. The blending solution includes no coal beneficiation plants.
5. The blended coal would be sold largely to central and east-central Iowa users and to Iowa users along the Mississippi River. Iowa underground mine coal would be sold directly to central Iowa coal users.
6. The basic mode of transportation for blended coal from the blending plant to coal users would be

trucks. The Chillicothe plant would be the only blending plant that would ship by rail. The Iowa underground mine coal would also be transported to Iowa users by truck. Nearly 77 percent of the nonblended out-of-state coal would be transported in 100-car unit trains to Iowa users.

7. The market for blended coal is almost evenly divided among coal users with the SO_2 emission standards of five-, six-, and eight-pounds of SO_2 emissions per million Btu.

8. About two-thirds of the blended coal run through coal blending plants would be 100 percent Wyoming coal. Therefore, the blending plants could be considered as basically transshipment points that receive low FOB priced Wyoming coal in 100-car unit trains and distribute the Wyoming coal in smaller shipment sizes to the Iowa users. Only one-third of the coal shipped from blending plants would be a blend of raw Iowa strip mine coal and Wyoming coal. This blend of Iowa coal and Wyoming coal would have a lower estimated FOB price at the blend plants than estimated FOB price at the blend plant for 100 percent Wyoming coal. After this raw Iowa strip mine coal would be exhausted, a blend of the next "best" Iowa coal would have a higher estimated

FOB price at the blend plants than 100 percent Wyoming.

9. Most of the investment costs in coal beneficiation plants and in upgrading individual coal user receiving capacity to the next larger shipment size in Solution I would be shifted to building four blending plants that can receive coal by 100-car unit trains in Solution II.
10. If the raw Iowa coal cannot be efficiently burned in the Iowa boilers, either beneficiating Iowa strip mine coal or transshipment of low sulfur Wyoming coal would lower the total cost of Iowa's 1980 coal requirements over the current coal distribution system.

Areas of Further Study

Iowa surface mine location, annual production, and coal quality are basic inputs into the model. These inputs were developed from results of the Iowa Geological Survey. The results of this analysis depend on the accuracy of Iowa mine data. Due to the deep underground location and thinness of Iowa coal seams and the small scale of Iowa mining operations and relatively high costs, further data accumulation on Iowa coal reserves and the quality of the Iowa coal would improve the results.

Iowa coal prices were based on the estimated costs of opening, operating, and reclaiming a mine under average mining cost operation. Consideration of alternative price levels would indicate the impact of the domestic price.

This analysis assumed that raw Iowa strip mine coal blended with low sulfur Wyoming coal could be efficiently burned in Iowa boilers. The compatibility of burning raw Iowa strip mine coal in Iowa boilers should be examined. If raw Iowa strip mine coal blended with low sulfur Wyoming coal can not be efficiently burned in Iowa boilers, then other alternatives should be considered. Solution I indicated that beneficiating Iowa coal would lower the total cost of supplying the 1980 Iowa projected coal consumption. Solution II indicated that approximately two-thirds of the Wyoming coal shipped to blending plants would not be blended with raw Iowa strip mine coal. Thus, an examination of transshipment of low sulfur Wyoming coal in comparison to the beneficiation alternative should be considered assuming the blended coal can not be efficiently burned in Iowa boilers.

An area of further research may be to consider the economics of stack scrubbing. This area should be analyzed as to the impact on the blending of high sulfur coal with a low sulfur coal.

BIBLIOGRAPHY

1. Avcin, Matthew J. "Estimated quantity and quality of Iowa coal reserves by county." Unpublished research. Iowa Geological Survey, Iowa City, Iowa, 1976.

2. Baumel, C. Phillip, Thomas P. Drinka, and John J. Miller. "The economics of alternative coal transportation and distribution systems in Iowa." Unpublished report. Department of Economics, Iowa State University, Ames, Iowa, 1978.

3. Baumel, C. Phillip, John J. Miller, and Thomas P. Drinka. An economic analysis of upgrading branch rail lines: A study of 71 lines in Iowa. National Technical Information Service Rep. No. PB-251978/AS, Springfield, Virginia, March 1976.

4. Boehlje, Michael, and James D. Libbin. "Economics of mining coal in Iowa." Staff paper series No. 47. Department of Economics, Iowa State University, Ames, Iowa, March 1977.

5. The Des Moines Register. "Biggest Iowa coal mine shut: Industry in trouble." Des Moines, Iowa, January 29, 1977.

6. Eldridge, Charles Lane. "The potential for improved transportation of raw and beneficiated coal in Iowa." Unpublished M.S. thesis. Iowa State University, Ames, Iowa, November 1977.

7. Federal Energy Administration. National energy outlook. Washington, D.C.: Author, February, 1976.

8. Hanline, D. "An economic determination of the number of sites and site locations for coal blending plants in Indiana." Unpublished M.S. thesis. University of Purdue, 1975.

9. Linn County. Regulation number 1-72, Air pollution. Linn County Board of Health, Cedar Rapids, Iowa, effective January 1, 1975.

10. Rules and regulations, Chapter 5, Air pollution control, article 9, division 2, section 5-27(a). Polk County Local Board of Health, Des Moines, Iowa, effective November 3, 1972.

11. Smith, Gerald W. Engineering economy: Analysis of capital expenditures. Ames, Iowa: Iowa State University Press, 1970.

12. State of Iowa. Iowa administrative code, section 400-4.3(3)a (sections 1, 2, 3, and 4). Des Moines, Iowa, effective July 19, 1976.

13. U.S. Congress, Public law 95-87, 95th Congress, 91 Stat. 445, August 3, 1977.

14. U.S. Department of the Interior, Bureau of Mines. Bituminous coal and lignite distribution. Washington, D.C.: Author, various issues.

15. U.S. Department of the Interior, Bureau of Mines. Bituminous coal and lignite distribution, calendar year 1976. Washington, D.C.: Author, 1977.